FINAL REPORT
VOLUME II
OF
A DESIGN STUDY OF A HELIUM RECOVERY SYSTEM FOR MILA

John F. Kennedy Space Center
National Aeronautics and Space Administration

NASA Contract No. NAS 10-1472

Air Products and Chemicals INC.

NAS10-1472

FINAL REPORT

VOLUME II

OF

"A DESIGN STUDY OF A HELIUM RECOVERY

SYSTEM FOR MILA"

John F. Kennedy Space Flight Center

National Aeronautics and Space Administration

[redacted]

Prepared by:

AIR PRODUCTS AND CHEMICALS, INC.

Allentown, Pennsylvania

FOREWORD

This report consolidates the information gathered during Phases I, II, and III of the helium recovery study. The report includes tabulated source data and calculations to support the conclusions presented.

The overall design study consists of three volumes:

Volume I	Synopsis of a Design Study of a Helium Recovery System for MILA.
Volume II	Final Report of a Design Study of a Helium Recovery System for MILA.
Volume III	Helium Usage and Recovery Equipment Supporting Data.

SCOPE

23931

The study described in this report evaluates various methods for recovering and repurifying the helium gas required for the flight preparation and launch of space vehicles at the Merritt Island Launch Area. In addition, it develops and justifies preliminary design for the system(s) considered to be most advantageous. The study is conducted in three phases.

Phase I of this study investigates the quantity and the locations of recoverable helium from the Saturn V - Apollo vehicle operational system at Launch Complex 39, MILA. The helium to be recovered is used for checkout of the Saturn V Space Vehicle at the various areas of LC-39, i.e., the pad area, vertical assembly building (VAB), the converter-compressor facility (CCF), and the various checkout buildings associated with the Apollo Spacecraft. In addition, the usage data was expanded to include the Saturn IB complexes 34 and 37 and associated systems.

Phase II of this study evaluates the various recovery and repurification system concepts and/or combination of concepts for application to the Saturn vehicle operation systems.

Phase III develops and justifies preliminary designs for the system(s) considered to be most advantageous for helium recovery and repurification at MILA.

This study is prepared by Air Products and Chemicals, Inc., under National Aeronautics and Space Administration Contract NAS10-1472.

Bulkoo

SUMMARY

Phase I - Helium Usage and Availability

The proposed quantity and uses of helium to check out and launch one Saturn V space vehicle at Launch Complex 39 were investigated under Phase I of this study. It was found that the total quantity of Grade A helium required is 69,500 pounds. Of this quantity, 55,300 pounds can be considered recoverable; 2,800 pounds is lost during the flight of the vehicle, and 11,400 pounds is physically lost during checkout and test operations.

Most of the recoverable helium, 27,800 pounds per vehicle, is available at the pad. Lesser amounts are available elsewhere - 25,400 pounds at the VAB, 1,500 pounds at the CCF, and 600 pounds within the industrial area.

The Saturn V - Apollo program also has requirements for Grade AA helium for checkout of the Apollo spacecraft. Since present information is limited as to its availability, its exact purity requirements, and its uses, this source of recoverable helium is excluded from this report. It appears that this quantity is negligible.

Secondary emphasis during this phase was placed on investigating the helium usage associated with the Saturn IB vehicles at Pads 34 and 37. It was found that a total of 16,005 pounds of helium is required to check out and launch one Saturn IB vehicle. Of this amount, it is feasible to recover 13,200 pounds. Flight requirements are 950 pounds.

Phase II - Helium Recovery Systems Evaluation

Evaluation work completed in Phase II of this study was performed in three major steps:

1. Investigation of helium purification cycles.
2. Investigation of contaminated helium gas-holding equipment.
3. Investigation of alternate helium recovery systems.

A general procedure followed throughout Phase II was the inclusion for study of as many different variations as possible for each step. These variations were evaluated by three general criteria: (1) economic advantage, (2) operational difficulty, and (3) amount of development necessary to obtain a workable system.

1. Helium Purification Cycles

   The seven different cycles investigated were:

   a. Cases I & IA - Cryogenic Separation and Adsorption at the VAB.

b. Case II - Catalytic Oxidation and Misch Metal Reaction at the Pad.

c. Case III - Catalytic Oxidation and Cryogenic Adsorption at the Pad.

d. Case IV - Catalytic Oxidation and Cryogenic Adsorption at the Pad and the VAB.

e. Case V - Catalytic Oxidation and Ethane Scrub at the VAB and the Pad.

f. Case VI - Thermal Diffusion.

g. Case VII - Gaseous Diffusion.

Cases VI and VII were eliminated because of their high operating cost and because they need further development to become workable.

The remaining cycles were evaluated by relative comparisons, Case I-A being used in conjunction with Case II or with Case III to provide a system capable of operation at the VAB and at the pad.

Case IV was found to be the most economical system in this evaluation. However, the combination of Case I-A and Case III may have some advantage as the number of launches per year increases. For this reason, it is recommended that Case IV be selected as the best cycle, but that the combination of Case I-A and Case III be investigated further in the 12 to 24 launches per year range.

2. Helium Storage Equipment

The different types of storage investigated were:

a. Steel gasholders

b. Hypalon-coated, double-walled, nylon hemispheres

c. Urethane-coated, double-walled, nylon half cylinders

d. Neoprene-coated, double-walled, nylon hemispheres

e. Steel cylinders at various pressure ratings

f. Nonrigid airships

After collecting information from various commercial sources, types a, b, c, and d, above, were evaluated to determine the most economical type of fixed low-pressure storage. Of these, type b appeared to be the best choice.

An evaluation of storage at higher pressures, type e above (in conjunction with some low-pressure storage for surge), was evaluated for various pressure levels. It was found that low-pressure storage type b, the Hypalon-coated hemisphere, remained the most economical. The nonrigid airships of type f were eliminated because high development costs are involved.

3. Alternate Helium Recovery Systems

   a. Alternate 1 - Fixed plant, fixed low-pressure storage, low-pressure pipeline (Fig. 9)

   b. Alternate 2 - Fixed plant, fixed low-pressure storage, high-pressure impure gas trailers (Fig. 10)

   c. Alternate 3 - Mobile plant, fixed low-pressure storage, high-pressure pipeline (Fig. 11)

   d. Alternate 4 - Mobile plant, fixed low-pressure storage, high-pressure pure helium trailers (Fig. 12)

   e. Alternate 5 - Fixed plant, mobile storage (Fig. 13)

   f. Alternate 6 - Mobile plant, fixed low-pressure storage, mobile compressor (Fig. 14)

   g. Alternate 7 - Fixed plant, combined storage, low-pressure pipeline (Fig. 15)

Alternate 4 was eliminated immediately because it was duplicated and simplified by Alternate 6. Alternate 5 was eliminated after discussion with Goodyear Tire and Rubber. They indicated that mobile storage would be too expensive because of development costs. The remaining alternates were evaluated by comparison, and the most economical was found to be Alternate 7, a fixed helium purification plant combined with low-pressure storage at the CCF and low-pressure pipelines from the VAB and the pads to storage.

After the recovery systems for Complex 39 were evaluated, a similar investigation was performed on helium recovery and purification for the Saturn IB at Complexes 34 and 37. The findings of the previous investigation were used wherever possible in this portion of the study. Four alternate recovery systems were evaluated:

1. Combined low-pressure storage, fixed plant. (Fig. 18)

2. Combined low-pressure storage, high-pressure impure gas trailers, use of plant at Complex 39. (Fig. 19)

3. Combined low-pressure storage, low-pressure pipeline, use of plant at Complex 39. (Fig. 20)

4. Combined low-pressure storage, low-pressure piping from pads to storage, mobile purification plant. (Fig. 21)

The most economical system was found to be the third alternate, which consisted of: (a) combined low-pressure, fixed storage of coated-nylon construction located near the CCF and fed by pipeline from Complex 34 and Complex 37; (b) 1-1/2 inch low-pressure pipeline from this storage to the storage for the purification plant at Complex 39; and (c) use of the purification plant at Complex 39. An incremental cost for the use of this plant is included in Alternates 2 and 3.

Phase III - Preliminary Design of the Helium Recovery System

The preliminary design of the helium recovery system, performed in Phase III of this study, consisted of determining optimum storage capacity and plant size, designing an optimum process cycle, and developing cost estimates in relation to launch rates as well as broad design parameters which would guide the development of a satisfactory final design.

Several factors which directly affect the size of low-pressure storage were studied in detail. It was determined that the addition of incremental storage will pay for itself if used but 10 times. The storage has thus been sized to capture all of the helium which it is predicted will be used, and no "use-peaks" will be vented. An ambient temperature of 75°F has been determined from published weather data to be the optimum design temperature. Using plots of the usage pattern for each vehicle operation sequence of interest, a graphical solution was made to determine the most economical combination of plant capacity versus required storage size. Finally, an on-stream factor and usage pattern safety factor were incorporated in the design storage size.

Prior to final preliminary sizing of the process equipment, several studies were undertaken to determine the relative economic advantages of changing certain process conditions to reduce liquid nitrogen consumption. Attention was focused on liquid nitrogen consumption because it constitutes the largest single operating cost. As a direct result of these studies, an additional heat exchanger and a vacuum pump are added in the final process design. The heat exchanger provides additional recovery of refrigeration for precooling, and the vacuum pump permits a lower process stream temperature so that more contained nitrogen is removed by phase separation. In addition, it was determined that the most economical system operating pressure is 155 psia, the lowest possible according to the ground rules. It was also decided to use a nonlubricated compressor in the cycle to prevent poisoning of the deoxo catalyst beds.

The process cycle provides for the removal of hydrogen by catalytic oxidation, forming water, which is removed by condensation and adsorption. Nitrogen is removed by condensing a portion of it at -338°F, and adsorbing the remainder on charcoal at -290°F.

The investment for a helium recovery and purification system composed of a purification plant using the previously described cycle, low-pressure coated-nylon storage containers, low-pressure contaminated helium compressors, and a low-pressure pipeline was calculated for four helium source combinations at four different launch rates each. This investment is found in Table XII and in Figure 30 and ranges from a minimum of $1,629,150 for 4 Saturn V launches per year with recovery at the VAB only, to a maximum of $4,118,940 for 18 Saturn V launches per year and 12 Saturn IB launches per year with recovery at the VAB and at all of the launch pads.

Operating costs as found in Figure 31 include labor, maintenance, chemicals and lubricants, electricity, water, oxygen, and liquid nitrogen and also general and administrative costs on these items.

The combined total of the annual operating costs and the annual depreciation charges divided by the annual weight of helium recovered yields the cost of purification. This cost in dollars per pound of helium recovered, as shown in Table XIII and Figure 32, ranges from a maximum of $3.08/lb. for 4 Saturn V launches per year with recovery at the VAB only, to a minimum of $.58/lb. for 18 Saturn V launches per year and 12 Saturn IB launches per year with recovery at the VAB and at each of the pads.

As shown in Figures 33 and 34, these recovery costs can yield potential savings ranging from a minimum of $142,000 per year, or $1,420,000 for a 10-year program, to a maximum of $4,250,000 per year or $42,500,000 for a 10-year program.

Translated into payout periods, Table XIV and Figure 35 show all systems considered as acceptable with payout periods of less than 5 years, the limit established in the ground rules of this study.

This study recommends that a helium recovery system be installed at launch Complexes 34, 37, and 39 for recovery of the helium used in the Saturn program.

TABLE OF CONTENTS

Page

Page

Page

APPENDIXES

TABLES

FIGURES

DRAWINGS

PART I

INTRODUCTION

A. GENERAL

Helium gas will be used for checkout and launch purposes for all Saturn vehicle operation systems at MILA and at Complexes 34 and 37. Uses of helium which have been established are:

1. Blanket gas for all LH_2 propellant tanks of the Saturn V and Saturn IB vehicles.
2. Ullage pressurization of all tanks on all Saturn V and Saturn IB stages.
3. Pressure testing of all tanks of Saturn V and Saturn IB vehicles.
4. Pressurized draining and purging of all tanks of the S-II and S-IVB stages.
5. Pressurization of control spheres for various subsystem checkouts and tests.
6. Thrust chamber purge and cooldown of S-II and S-IV stages.
7. Pressurization and purging in Apollo system checkout.
8. Regeneration of the proposed helium purification system at the converter-compressor facility of Complexes 34 and 37; no helium purification unit is presently planned for the converter-compressor facility of Complex 39.
9. Inerting of the LH_2 transmission fill and drain line.

The various areas at which the operations requiring helium are performed will be Launch Complex 39 for the Saturn V, Launch Complexes 34 and 37 for the Saturn IB, and the industrial area. Launch Complex 39 is defined as the vertical assembly building, compressor-converter facility, and the pad areas.

This report summarizes the data collected and revised during Phase I of this study and lists the quantity and location of all helium used and the quantity and location of recoverable helium if economics dictate that recovery should be made.

In addition, all Phase II evaluation work associated with helium purification cycles, helium gas holding equipment, and alternate helium recovery systems for Complexes 34, 37, and 39 are reported herein.

Preliminary design of the most advantageous recovery schemes will be developed and justified during Phase III of this design study.

B. PURPOSE

The purpose of this study is as follows:

1. Investigate and determine the quantity, characteristics, and location of recoverable helium from the Saturn vehicle operational system at MILA.

2. Perform technical, operational, and economic evaluations on all alternate helium recovery systems concepts that may be adapted to the various areas and operations of the Saturn systems at MILA.

3. Develop the preliminary design of the most economical and feasible recovery system(s), complete with a description of operational procedures, cost of installation, and capital expenditure justification.

C. GROUND RULES AND BASIC ASSUMPTIONS

The following ground rules and basic assumptions have been established with NASA-KSC for this study.

1. A recovery system is defined as that system which captures and holds contaminated helium, purifies it to Grade A quality, and returns it to the storage facility for reuse.

2. The maximum time that contaminated helium shall remain at Cape Kennedy is 2 weeks, i.e., all contamined helium in storage must be processed within 2 weeks after a vehicle has been processed either at the pad or the VAB. Contaminated helium is defined as all helium that has been released from storage for checkout and launch purposes and all leakage.

3. Economics shall be based on an amortization period of 10 years and a payout period of 5 years.

4. The cost of helium shall be $3.50/lb. f.o.b. Amarillo, Texas, or $4.50/lb.* delivered at Cape Kennedy, including 15 days demurrage.

5. Cost of returning contaminated helium from Cape Kennedy to the Bureau of Mines for purification shall be 80% of that charged for shipping Grade A helium to Cape Kennedy. This helium recovery scheme will not

*See "Report on Long-Range Helium Transportation Optimization Study for NASA, KSC, MILA" by United States Department of the Interior, Bureau of Mines, Helium Activity for a revised cost of helium delivered at Cape Kennedy.

be considered in this study.

6. Liquid helium storage or transport shall not be considered in this study. It shall be assumed that helium is delivered to Cape Kennedy in high-pressure railroad cars.

7. The following cost factors shall be used in this study:

   a. Power - 1.225¢/KWH

   b. Water - 10¢/1000 Gallons

   c. Plant operation labor rates:

Classification	Rate*	% Fringe Benefits
(1) Superintendent	$ 192.70/week	20
(2) Assistant Superintendent	161.54/week	20
(3) Operator	3.44/hour	15
(4) Operator Helper	3.24/hour	15
(5) Maintenance Man	3.44/hour	15
(6) Maintenance Helper	3.29/hour	15
(7) Material Handler	2.57/hour	15

*Labor rates listed do not include fringe benefits.

   d. Delivered price of cryogenic liquids and propellants to Cape Kennedy shall be as follows:

      (1) LN_2 - $ 39.50/ton

      (2) LOX - 38.25/ton

      (3) LH_2 - 1700/ton ($0.85/lb.)

   e. NASA General and Administrative Rate - 10%

   f. No interest charge is included for investment funds (cost of capital financing).

8. All helium recovery equipment within the complex except the storage shall be designed to withstand the following (whichever is greater):

   a. Overpressure experienced during a normal launch; no allowance is included for a catastrophe.

   b. Hurricane wind velocity of 125 mph.

   c. The storage containers shall be designed to sustain 75-mile-per-hour winds. For hurricane force winds, it is contemplated that the storage containers will be deflated and covered.

9. The checkout and launch of one Saturn V - Apollo vehicle will normally be performed within a 58-working-day period (one 8-hour shift per day, 5 days per week).* The checkout and launch cycle for one Saturn IB is 40 working days (one 8-hour shift per day, 5 days per week) at Launch Complexes 34 and 37. The checkout and launch procedure for the Saturn IB is to be identical with that of the Saturn V, except for those operations which are duplicated due to the location of the Saturn V at checkout. For example, whereas the Saturn V is pressure tested at both the VAB and the pad, only one such operation is required on the Saturn IB, since all checkout and launch operations are performed at the same location.

10. Utilities are assumed to be available at equipment battery limits.

*According to information received from NASA 3/3/65, the latest schedule for checkout and launch of a Saturn V - Apollo vehicle is 13 weeks; for a Saturn IB, the latest schedule is 58 working days.

PART II

HELIUM USAGE AND AVAILABILITY

A. GENERAL

This phase of the study investigated the quantity and location of recoverable helium for the Saturn V system at Launch Complex 39, MILA, and the various checkout buildings associated with the Apollo spacecraft, and for the Saturn IB at Complexes 34 and 37.

A detailed tabulation of the helium used per Saturn V checkout and launch operation is presented in Table I. This data was developed from the rates and quantities stated in the Saturn V Vehicle Fluid Requirements, Drawing Numbers 13M50096 (S-IC), 13M50097 (S-II), and 13M50098 (S-IVB) in conjunction with checkout sequences obtained from the various personnel at Kennedy Space Flight Center, Cape Kennedy, Florida, and Marshall Space Flight Center, Huntsville, Alabama. A report of the personnel contacted and data obtained appears in Appendix B.

Figure 2 illustrates the weight of recoverable helium per day based on a checkout and launch sequence requiring a 58-working-day schedule. Figure 3 illustrates the total volume of contaminated helium per day of a 58-working-day checkout and launch schedule.

A detailed tabulation of the helium used for each Saturn IB checkout and launch cycle is presented in Table II. This data was developed from rates and quantities stated in Saturn IB Vehicle Fluid Requirements, Drawing Numbers 13M20097 (S-IB) and 13M20098 (S-IVB). This data was used in conjunction with a checkout and launch sequence identical with that of the Saturn V Vehicle, but modified by deleting one each of the identical operations performed on the Saturn V at both the VAB and pad and by substituting a checkout and launch cycle of 40 working days.

Figure 1 illustrates the weight of recoverable helium per working day based on a checkout and launch sequence requiring a 40-working-day schedule. Figure 1A illustrates the volume of recoverable contaminated helium per working day of a 40-working-day schedule.

Contaminants in the recoverable helium were calculated by the methods shown in Appendix A, Sample Calculations, and are included in Tables I and II.

B. DISCUSSION

The checkout and launch cycle of the Saturn V Vehicle requires 69,491 pounds of Grade A helium. Of this quantity, it is feasible to recover 55,307 pounds at the following locations: 25,398 pounds at the vertical assembly building 27,779 pounds at the pad, 630 pounds at the industrial area, and 1,500 pounds at the compressor-converter facility. Flight requirements account for the loss of 2,745 pounds of Grade A helium, and the remaining helium is physically unrecoverable.

The Saturn IB checkout and launch operations require 16,005 pounds of Grade A helium of which 12,500 pounds is recoverable. All recoverable helium is obtained at pad 34 and/or pad 37, since all checkout and launch operations are performed in the pad area. Flight requirements consume 950 pounds of Grade A helium.

An indeterminate amount of Grade AA helium is used in spacecraft checkout and launch, however it appears that this quantity is negligible.

Average composition of the contaminated helium recovered from the Saturn V is as follows:

	VAB Only	Pad Only	Composite
Helium	97.4%	90.5%	93.8%
Nitrogen	2.6%	3.1%	2.8%
Hydrogen	0.0%	6.4%	3.4%
Oxygen	56 ppm	0.0%	27 ppm

The overall composition of recoverable contaminated helium associated with the Saturn IB is helium - 93.0%; nitrogen - 2.3%; hydrogen - 4.7%; and oxygen - 40 ppm.

PART III

HELIUM PURIFICATION CYCLES

A. GENERAL

This study considered seven different purification cycles for repurifying the recovered helium to Grade A quality. Since preliminary Phase I data was used to develop the cycles being evaluated, the final cycles chosen for further study vary slightly in the preliminary design phase. These changes, however, will not affect the validity of the results. The different cycles are:

1. Cases I and IA - Cryogenic Separation and Adsorption.

   These cycles are designed to remove water, nitrogen, and oxygen contaminants from helium. Therefore, they apply only to the helium recovered from the VAB area. The major contaminant at the VAB is nitrogen. These cycles are identical in every respect except that Case I is sized to handle four times the flow rate of Case IA. For a complete purification system, Case I or IA must be used in conjunction with Case II or Case III.

2. Case II - Catalytic Oxidation and Misch Metal Reaction.

   This cycle is designed to remove up to 16% hydrogen and up to 0.1% nitrogen or oxygen from helium. Thus it applies only to operation at the pad, where hydrogen contamination from tanking tests occurs and where the amount of nitrogen or oxygen included in the stream is very small. For a complete purification system, Case II must be used in conjunction with Case I or Case IA.

3. Case III - Catalytic Oxidation and Cryogenic Adsorption.

   This cycle is designed to handle the same conditions as those set for Case II, operation at the pad only. This cycle must be used in conjunction with Case I or IA for a complete purification system.

4. Case IV - Catalytic Oxidation and Cryogenic Separation and Adsorption.

   This cycle has been designed to purify contaminated helium collected from either the VAB or pad areas.

5. Case V - Catalytic Oxidation and Ethane Scrubbing.

   This cycle is designed to remove all contaminants from the helium collected at either the VAB or pad area.

6. Case VI - Thermal Diffusion.

7. Case VII - Gaseous Diffusion.

A brief description of each cycle and a discussion of each follow in Section B and C respectively.

In addition, a preliminary investigation was made into the various other methods which are available for removing hydrogen from a helium-rich stream. The advantages offered by the catalytic oxidation method for removing hydrogen are included in Section C.

B. PROCESS DESCRIPTION OF HELIUM PURIFICATION CYCLES

1. Cases I and IA - Cryogenic Separation and Adsorption.

The flowsheet for these cases is shown in Figure 4.

Contaminated helium is withdrawn from storage and compressed to 225 psia in the main compressor (01.20). Compressor oil contamination is removed by passing the process stream through the in-line oil coalescer (02.54), the oil separator (02.53), one of the pair of driers (03.10), and the K-filter (02.52). The driers also remove any water vapor which is contained in the contaminated helium. The dry process gas is then cooled in the main heat exchanger (05.21) against the returning product stream and the cold nitrogen vapor from the reboiler (05.22). Further cooling takes place in the reboiler (05.22), which contains liquid nitrogen on the shell side.

The resulting low temperature of the contaminated helium gas is such that all nitrogen in excess of 6% condenses to form a liquid phase. This liquid nitrogen phase is removed by passing the gas through the phase separator (07.81). The remaining nitrogen and the small amount of oxygen contained in the stream are removed by adsorption in the charcoal adsorbers (08.41). The cold pure helium stream is then warmed to ambient temperature by exchanging heat with the contaminated helium gas in the exchanger (05.21), as described above. The driers (03.10) must be reactivated once every 8 hours to remove the adsorbed water vapor. This is done manually by valving one of the pair of driers into the reactivation circuit, while the other is in the main process stream circuit. The helium reactivation gas is circulated by the drier reactivation compressor (01.22). The gas is heated to 375°F in the drier reactivation heater (03.17), then passed through the driers. Over a 3-hour period, this heats the drier to 375°F. The hot gas leaving the drier is cooled to ambient temperature in the water heater (03.11) before re-entering the suction side of the compressor. At the end of the 3-hour heatup portion of the reactivation cycle, the drier is cooled back to ambient temperature by a reverse flow of the gas stream bypassed around the heater. The reactivated drier is then valved into the main stream and the reactivation cycle is repeated on the other drier during the next eight-hour period.

Regeneration of the adsorbers (08.41) is also performed on an 8-hour cycle. As with the driers above, one of the pair is regenerated while the other is in service. Helium regeneration gas is circulated by the reactivation compressor (01.21). The gas is heated in the adsorber heater (08.43), in turn heating the adsorber (08.41) from the liquid nitrogen temperature level until the adsorber outlet gas reaches 100°F. At this point, the heater (08.43) is shut off, and the system is depressurized and purged with pure helium gas. System gas is vented to the atmosphere. The adsorber is subsequently pressurized with product helium and cooled down to liquid nitrogen temperature by cooling the gas in the exchanger (08.25) with liquid nitrogen and circulating it through the adsorber (08.41). The water heater (08.23) warms the reactivation gas from the low temperature at which it leaves the adsorber (during both heatup and cool-down) to ambient temperature before the gas enters the suction side of the compressor (01.21).

The liquid nitrogen storage tank (16.10) provides a supply of liquid nitrogen for the adsorber cooldown exchanger (08.25) and for the reboiler (05.22). For normal operation, the storage tank will require refilling every 2 days.

2. <u>Case II - Catalytic Oxidation and Misch Metal Reaction</u>.

The flowsheet for this case is shown in Figure 5.

The contaminated helium from storage is compressed to 225 psia in the main compressor (01.20). Compressor oil contamination is removed by successively passing the stream through the in-line oil coalescer (02.54), the oil separator (02.53), one of a pair of oil adsobers (02.51), and the K-filter (02.52).

Hydrogen is removed by adding oxygen to the process stream and passing the stream through the deoxo catalyst (02.10). With the aid of the catalyst, the added oxygen reacts with the hydrogen to form water. The reaction raises the temperature of the process stream to a maximum of 900°F. The stream is then cooled back to ambient temperature in the exchanger (05.70). This causes some of the water vapor to condense, and the condensed portion is removed in the water separator (03.13). The temperature level of 900°F limits the amount of hydrogen converted to form water to 4% in a single stage. Thus, for the design requirement of 16%, it is necessary to provide four identical stages in series. System control is accomplished automatically on the last stage by the hydrogen sensor-controller labeled XIC on the flowsheet. This instrument automatically controls the amount of oxygen added to the last stage, so that the hydrogen outlet concentration is less than 0.1%. Control of the other stages is provided by manual adjustment of the oxygen inlet to keep the gas-stream temperature below 900°F, as shown by the temperature indicators (TI).

Final drying takes place in the drier (03.10), located downstream of the final stage water separator (03.13). The reactivation cycle is identical with that described in detail for the drier system in Cases I and IA above. Briefly, the 8-hour reactivation cycle uses the heater (03.17) for heatup and bypasses the heater during cooldown. Circulation of regeneration gas is provided by the compressor (01.22), and desorbed water is removed from the regeneration gas by cooling and condensing in the precooler (03.11), then removing liquid in the water separator (03.12).

Residual hydrogen and nitrogen impurities are removed by reacting them with Misch metal, a mixture of rare earth metals. These reactions occur at a temperature of 1100°F. The process stream is preheated by heat exchange with returning product in the preheat exchanger (05.71). Final heating is done by the electric heater (05.72). The high-temperature gas then passes through the Misch container (02.11), and the pure product is cooled to ambient temperature by heat exchange with the impure process stream in the preheat exchanger (05.71).

3. Case III - Catalytic Oxidation and Cryogenic Adsorption.

The flowsheet for this case is shown in Figure 6.

The cycle is exactly the same as Case II through the drier (03.10). Process gas is compressed in the compressor (01.20), passes through oil removal equipment (02.54), (02.53), (02.51), and (02.52), then reacts by stages with added oxygen to form water in the deoxo catalyst beds (02.10), cools in the exchanger (05.70), and loses the resulting water droplets in the water separator (03.13). Final drying occurs in the drier (03.10), which has an 8-hour regeneration cycle as described fully in Cases I and IA above. The drier to be regenerated is heated for a period by gas passing through the heater (03.17), then cooled by bypassing the heater. Regeneration gas circulation is provided by the compressor (01.22). Desorbed water from the drier is condensed in the precooler (03.11) and removed in the water separator (03.12). The sensor-controller, XIC, is set to provide a slight excess of oxygen instead of an excess of hydrogen as in Case II. The basic difference between Case II and Case III lies in the method used to remove nitrogen and residual oxygen; low-temperature adsorption is used in place of Misch metal. Operation of the adsorption system is identical with that of Case I as described above with one exception. The phase separator (07.81) of Case I is not needed in Case III because the nitrogen content of the stream is too low for condensation into the liquid phase. The process stream, from which hydrogen and water have been removed, leaves the drier

(03.10) and is cooled by heat exchange with returning product in the exchanger (05.21). It is cooled further against liquid nitrogen in the reboiler (05.22), then passes through the adsorber (08.41) and is warmed to ambient in the main exchanger (05.21). Reactivation of each adsorber (08.41) is performed during alternate 8-hour periods by the regeneration circuit. From its -320°F operating temperature, the adsorber is warmed by helium, heated in the adsorber heater (08.43) and circulated by the reactivation compressor (01.21).

The gradually warming exit gas from the adsorbers is warmed to ambient in the preheater (08.23) before re-entering the compressor. When the adsorber outlet temperature reaches 100°F, the heater (08.43) is shut off, the system is purged, and cooldown through the exchangers (08.25A and B) is begun. When the adsorber reaches operating temperature, it can be valved back into the process stream circuit.

4. Case IV - Catalytic Oxidation - Cryogenic Separation and Adsorption.

The flowsheet for this case is shown in Figure 7.

The system equipment is identical with that used in Case III except for the addition of the liquid nitrogen phase separator (07.81), which enables the system to operate at the VAB as well as at the pad. At the VAB, the gas is compressed in the main compressor (01.20), passes through the oil removal equipment (02.54), (02.53), (02.51), and (02.52), bypasses the deoxo unit and its associated equipment (02.10), (05.70), and (03.13), and goes directly to the drier (03.10), with its associated regeneration equipment. After drying, nitrogen is removed by cooling the gas in the exchanger (05.21) and the reboiler (05.22), separating the condensed nitrogen in the phase separator (07.81), and adsorbing the remainder in the adsorber (08.41). Adsorber regeneration equipment consists of the heater (08.43) and the cooldown exchangers (08.25A and B).

At the pad, after compression and oil removal, the process stream passes through the four deoxo units (02.10), with intermediate cooling in the cooler (05.70), and removal of condensed water in the water separator (03.12). After the process stream is dried in the driers (03.10), the remaining nitrogen and oxygen are adsorbed in the nitrogen adsorption system (08.41) after cooling in the main exchanger (05.21) and the reboiler (05.22). Although in the system, the phase separator (07.81) is not in operation because of the low nitrogen content.

5. Case V - Catalytic Oxidation and Ethane Scrubbing.

The flowsheet for this case is shown in Figure 8.

This cycle is identical with Case IV except for equipment directly associated with final removal of nitrogen from the helium. In case

IV, this is done with the nitrogen adsorber (08.41) and its associated regeneration equipment. In Case V, nitrogen is removed by absorption in liquid ethane, a process commonly called an ethane scrub system. After compression and oil removal, the hydrogen (for pad operation) is removed by the deoxo units (02.10). After drying in the driers (03.10), the stream is cooled against itself in the main exchanger (05.21) and against liquid nitrogen in the reboiler (05.22), then passed through a phase separator (07.81) for removal of condensed liquid nitrogen (VAB operation).

The nitrogen-contaminated helium stream, after leaving the phase separator (07.81), enters the bottom of the adsorber (07.21), flows countercurrent to and in direct contact with the subcooled ethane liquid, and finally leaves from the top to enter the main exchanger (05.21).

Ethane, with the adsorbed nitrogen, leaves the bottom of the adsorber (07.21), expands to a lower pressure, and passes through an exchanger (05.37), where it is warmed by exchanging heat with the returning pure ethane stream. From the exchanger (05.37), the ethane stream enters the distillation column (07.11), where the nitrogen is removed from the ethane and is eventually vented to the atmosphere. Nitrogen-rich vapor from the top of the column (07.11), is condensed in the reboiler (07.12) against liquid nitrogen and flows to the Norway separator (07.14). Liquid from the separator (07.14) provides reflux to the column (07.11). The vapor, mostly nitrogen, is removed from the top of the separator (07.14), warmed by heat exchange with pure ethane in the exchanger (05.39), and is then vented to the atmosphere.

A small amount of liquid ethane is withdrawn from the bottom of the column (07.11), vaporized in the reboiler (07.13), and is returned as vapor reflux to the column (07.11). Pure liquid ethane is withdrawn from the bottom of the column (07.11), pressurized in the liquid pump (10.20), and subcooled in three exchangers, (05.39), (05.37), and (05.38). The pure, subcooled liquid ethane is then returned to the adsorber (07.21).

6. Case VI - Thermal Diffusion.

A preliminary investigation was made into the possibility of using a thermal diffusion process to remove nitrogen from the helium gas. A flowsheet is not shown for this cycle, since it readily became apparent that the scheme is not economically feasible.

Separation of gases by thermal diffusion is normally used only for gas mixtures such as isotopes, which are very difficult to separate in any other way. A description and analysis of the thermal diffusion process is given by Benedict.* Basically, the physical system is a heated wall placed very close to a cooled wall with the process gas flowing in the gap. Theory predicts, and practice usually substantiates, that the lighter component of the mixture will concentrate at the heated wall. By proper staging, almost any degree of separation is possible.

7. Case VII - Gaseous Diffusion.

Gaseous diffusion is a method for separating gas mixtures which utilizes the fact that the lighter molecules (e.g., helium) in a gaseous mixture travel faster, on the average, than the heavier molecules (e.g., nitrogen). If a mixture of gases at high pressure is continuously passed over a microporous barrier, the faster, ligher molecules will tend to concentrate by diffusing through the pores on the low-pressure side, leaving behind a mixture which is more concentrated in the slower, heavier molecules. By recompressing the diffused mixture and passing it over another microporous barrier, a further enrichment of the faster, lighter molecules occurs. Similarly, the nondiffused mixture is passed through another stage, which causes further enrichment of the slower, heavier molecules. By providing sufficient stages, a high degree of separation may be obtained.

C. DISCUSSION

Initial evaluation work in selecting a helium purification cycle involved the selection of the most practical and economical method for removing hydrogen from a helium-rich stream. The deoxo catalyst was selected, since it is a proven economical method. The relative advantages and disadvantages are discussed herein.

Final comparisons of the purification cycles were made, using Case IA (Cryogenic Separation and Adsorption) with Case II (Catalytic Oxidation and Misch Metal Reaction); Case IA (Cryogenic Separation and Adsorption) with Case III (Catalytic Oxidation and Cryogenic Adsorption); Case IV (Catalytic Oxidation and Cryogenic Separation and Adsorption); and Case V (Catalytic Oxidation and Ethane Scrubbing). Case VI (Thermal Diffusion) was eliminated because of high operating cost, and Case VII (Gaseous Diffusion) was eliminated because of the development work required prior to achieving a workable cycle. Detailed discussion of each complete cycle is included herein.

All estimated equipment cost, capital charges, and operating costs are tabulated in Tables III through VII.

*Benedict, M., "Multi-stage Separation Processes", Transactions AIChE, Volume 43, No. 2, February 1947.

1. Case IA with Case II.

This cycle processes 20 pounds per hour of contaminated helium at the VAB and 46 pounds per hour of contaminated helium at the pad. Assuming a series checkout operation, the same crew will be used to operate either plant as the checkout sequence dictates, i.e., the Case IA plant when the vehicle is in the VAB and the Case II plant when the vehicle is at the pad.

Total estimated comparative investment cost, as listed in Table IV, is $665,182, erected. For both plants, capital charges are $69,968 per year, and operating costs vary from $100,936 (Table V) for three launches a year to $127,045 (Table VI) for six launches a year. Total yearly costs, including capital charges, vary from $180,998 (Table VII) for three launches per year to $209,718 (Table VII) for six launches per year. A detailed breakdown of the equipment cost is contained in Table III.

This cycle can process a total of 66 pounds of contaminated helium per hour. However, it was eliminated from further evaluation, since a combination of Case IA with Case III proved more economical.

2. Case IA with Case III.

This cycle can also process 20 pounds of contaminated helium at the VAB and 46 pounds of contaminated helium at the pad. It is assumed that the same operating crew will be used for either plant, as proposed in the cycle previously discussed.

Total estimated comparative investment cost, erected, is $734,620 (Table IV); capital charges are $73,462. Operating costs vary from $94,831 per year (Table V) for three launches per year to $108,940 per year (Table VI) for six launches yearly.

Total yearly costs vary from $177,776 for three launches per year to $193,296 for six launches per year (Table VII). Equipment costs are detailed in Table III.

This cycle can process a total of 66 pounds of contaminated helium per hour. Although not as economical as Case IV, it would appear to be a more economical cycle at higher yearly launch rates and is therefore recommended for further study in Phase III.

3. Case IV.

This cycle is capable of processing 46 pounds of contaminated helium per hour from either the VAB or the pad. Total estimated comparative investment, erected, is $407,165; yearly capital charge is $40,717

(Table IV). Operating costs vary from $90,125 per year (Table V) for three launches a year to $104,234 per year (Table VI) for six launches a year. Total yearly costs vary from $139,855 for three launches per year to $155,374 for six launches per year respectively (Table VII). Detailed estimated equipment costs are tabulated in Table III.

Since this cycle is the most economical of all considered, it is recommended for further study during Phase III.

4. Case V.

This cycle is capable of processing 46 pounds of contaminated helium per hour from either the VAB or the pad. Total estimated comparative investment, erected, is $418,332; yearly capital charge is $41,833 (Table IV). Yearly operating costs vary from $90,318 (Table V) for three launches per year to $104,408 (Table VI) for six launches per year. Total annual costs, including capital, vary from $141,183 for three launches per year to $156,572 for six launches per year (Table VII). Detailed estimated equipment costs are listed in Table III.

This purification process has been eliminated from the list of possibilities considered as a part of Phase II of the study for the following reasons:

a. The process does not show any marked economic advantage. In fact, it was slightly more expensive than the best case.

b. The reliability of such a system is very questionable, especially when compared to the low-temperature adsorption process. Although other low-temperature purification scrub systems are presently being operated by other companies, these systems are relatively inflexible because they are in continuous operation. In case of a shutdown, it is difficult to restart the units and establish equilibrium conditions. The problem of storing the scrub fluid during shutdown is also serious, since the makeup requirements of ethane can greatly influence system operating costs.

c. Because of the uncertainty of the design involved, especially concerning equilibrium data for the various operating conditions, some minimal amount of development work would have to be performed.

d. A scrub system is generally preferred for higher capacity plants, where the possibility for payout is easier to justify and where continuous operation is more desirable. For a processing plant of the type and size considered for this study, the low-temperature adsorption process appears to be a more standard and acceptable method of purification.

Based on the relatively good results with low-temperature adsorption and on the disadvantages of the scrub system listed above, the scrub system will be considered no further.

5. Case VI.

Preliminary investigation into the possibility of using a thermal diffusion process to remove nitrogen from helium gas indicated that this cycle was not economically feasible. An equation presented by Benedict (referenced in Section B above) is used to calculate the minimum possible energy requirements to effect the desired separation. For operation of the VAB only, heating of the wall would require 1×10^8 BTU/hr. If natural gas is used for heating, the minimum possible cost of gas allowance amounts to $2.80/lb. of helium received. Since the various other purification cycles indicate a cost, including all operating and capital charges, of less than half this amount per pound of helium received, it is obvious that this case is not economically feasible. It is therefore eliminated from future evaluation.

6. Case VII.

Past evaluation of gas diffusion processes for gas purification have proved these methods to be impractical when compared to cryogenic purification. This has been due mainly to the high compression and power requirements.

Presently, an investigation is being conducted into the economic feasibility of a new porous material for use with a gaseous diffusion process. Completion of this study is expected shortly, but even if positive results are obtained, a considerable amount of development work will be required before the system is completely evaluated and proven.

Based on the development effort required, it is recommended that the gas diffusion cycle be eliminated from further consideration in this study.

7. Evaluation of Methods for Removal of Hydrogen from a Helium Feed Stream.

The use of a deoxo catalyst for conversion of hydrogen to water, followed by drying of the effluent stream, was selected as the best method for purification of the helium feed stream. This choice was based on a comparison of the following processes:

a. Deoxo catalyst conversion.
b. Copper oxide catalyst conversion.
c. Distillation.
d. Adsorption.
e. Gaseous diffusion.
f. Thermal diffusion.

Gaseous and thermal diffusion were eliminated from the list of possibilities for removing nitrogen and oxygen from helium because of the high power requirements. These requirements are even higher, relatively, for removal of hydrogen from helium, because the respective molecular weights and boiling points are closer together.

Although it is relatively easy to remove nitrogen and oxygen from helium by distillation or adsorption both these processes are difficult compared to catalytic conversion in removing hydrogen from helium. This is true because catalytic conversion takes place at ambient temperature and requires only heat of reactivation for the driers. Adsorption and distillation would require heat exchange to a temperature level equal to or below that of liquid nitrogen, thereby requiring a substantial amount of refrigeration power.

Only two developed methods for hydrogen removal from a helium stream are offered at the present time. These are deoxo catalyst conversion and copper oxide conversion. The two processes are comparable in that they require no refrigeration below ambient temperature, and both require a drier system to remove the product of reaction water. The copper oxide process offers the advantage of complete conversion to within 1 ppm hydrogen, whereas the deoxo unit control is limited to about 0.1 percent excess hydrogen or oxygen. The copper oxide process, however, requires an elevated temperature of reaction of about 450°F, and requires dual vessels to permit switching for reactivation.

Since several of the helium-using operations at the pad result in some nitrogen contamination of the impure helium, the disadvantage of 0.1 percent oxygen in the process stream leaving the deoxo unit is minimized. This is because, with either a deoxo or a copper oxide unit, it is still necessary to remove the nitrogen impurity by low-temperature adsorption. The 0.1 percent oxygen can be removed by this same adsorber with an incremental addition to its size of only 5 to 10 percent.

The overall relative disadvantage of the copper oxide system can be seen by comparing the partial flowsheets shown in Figure 17. In each case, the equipment shown will completely remove the hydrogen from the helium stream. Equipment requirements both upstream and downstream of that in the figure are the same with the exception that the size of the low-temperature adsorber must be increased for the deoxo case. However, for the copper oxide case, the capital equipment expenditure is greater and operating costs are higher because of the power needed for process stream heating and for the reactivation cycle.

A final point is that although copper oxide has been used to remove traces of hydrogen impurities, it has not been used at the high hydrogen concentrations encountered here. Because the reaction is between the hydrogen in the stream and the copper oxide in the bed and requires no oxygen addition, it is impossible to use multiple stages for the reaction. The complete reaction will take place within a small portion of the bed, and the complete heat of reaction will also be released in that small volume, making it necessary to provide cooling within the bed itself. Since this would require a development program, it is not attractive.

PART IV

HOLDING EQUIPMENT FOR CONTAMINATED HELIUM GAS

A. GENERAL

A review was made of the commercially available storage containers for helium gas. These various types were then evaluated to determine the most economical unit for storing the contaminated helium gathered from space vehicle checkout and launch preparation at MILA. This evaluation was performed in two parts:

1. Various low-pressure containers (maximum design pressure of approximately 6 inches of water) such as gasholders, rigid tanks, and flexible bags were evaluated to determine the most economical type of low-pressure container.

2. Various storage pressure levels were evaluated to determine if a combination of higher pressure storage units (up to 435 psia design pressure) with low-pressure containers proves more economical than storing all gas at atmospheric pressure.

The results of these evaluations are summarized herein.

B. EVALUATION OF VARIOUS TYPES OF HOLDING EQUIPMENT FOR LOW-PRESSURE HELIUM GAS

A comparison was made of the various types of fixed storage, each of 1 million cubic feet (10,000 pounds) capacity, to determine significant cost differences, and thereby determine the most economical type. This comparison was made on the basis of total cost of storage over a 10-year period. This total cost includes not only equipment and erection investment but also maintenance, replacement, and operating costs over a 10-year period. The following types of storage were considered in this evaluation (see Figure 16):

1. GATC - A Wiggins Gasholder, fabricated by the General American Transportation Corporation. This is a cylindrical steel tank containing a movable piston sealed to the outer tank by a flexible membrane. This gasholder, though relatively expensive, requires no maintenance for its moving parts over the 10-year period.

2. CB&I - The Chicago Bridge & Iron "Vaporsphere" is similar to the Wiggins Gasholder though less expensive. It carries the Wiggins principle one step further by eliminating the movable piston and extending the flexible seal to replace it.

3. Goodyear - This is a double-walled hemispherical container fabricated by Goodyear Tire & Rubber Co. The gas-holding container is a sphere

of neoprene-coated nylon. The outside protective container is a larger sphere of hypalon-coated nylon. A blower is used to maintain the shape of the outside container.

4. Birdair - This structure is similar to Goodyear's in materials and construction and is fabricated by Birdair Structures, Inc. of Buffalo, New York.

5. Viron - This is a double-walled half-cylinder with quarter-spherical ends, fabricated of urethane-coated nylon by Viron Division of Geophysics Corporation of America. The inner container is the gas-holder.

Comparative cost estimates were developed for each type and are tabulated in Table VIII. A definite cost advantage can be achieved by using the coated nylon containers.

C. EVALUATION OF STORAGE PRESSURE

The largest percentage of investment of any helium gas recovery system at MILA is for the holding equipment for contaminated gas. In order to substantiate that storing this gas at low pressure (4 to 6 inches of water) is most economical, the costs of storing the contaminated helium gas at pressures of 75 psia, 265 psia, 365 psia, and 435 psia were compared to the cost of storing the gas at essentially atmospheric pressure in a CB&I "Vaporsphere". The CB&I container was chosen because cost data at all pressure levels were available from them, thereby insuring internally consistent results.

On the basis of series operation (six Saturn V launches per year), 995,000 SCF (9950 lb.)* of gas storage is required at the VAB. Surge control of atmospheric storage is needed regardless of the pressure level at which the gas is stored until processed. Because of this requirement, storage at any pressure other than essentially atmospheric becomes uneconomical because nearly half of the cost of low-pressure storage remains in the estimate.

Results of this evaluation are summarized in Table IX.

D. DISCUSSION

Since the use of flexible, low-pressure, gaseous storage containers has been relatively limited, a short discussion on these containers is presented here to answer questions about them which might arise.

Presently in use at NASA's Lewis Research Center, Cleveland, Ohio, are

*This volume includes a 20% safety factor in storage sizing.

two containers of the type proposed for use in a helium collection and purification system at LC-34, LC-37, and LC-39. The typical container is composed of an inner and an outer hemisphere.

The inner hemisphere, the helium container, is made of hypalon-coated nylon, and includes a ground diaphragm and an anchorage system.

The outer hemisphere protects the helium container. It is made of hypalon-painted, neoprene-coated nylon. The outer envelope is equipped with two blowers to keep it inflated with low-pressure (4 to 6 inches of H_2O) air. The hypalon serves as a weathering barrier and the neoprene serves as an ultraviolet light barrier which protects the nylon fabric. Since the neoprene is black and the hypalon white, preventive maintenance is made simple by painting the structure with hypalon when the neoprene starts to show through.

The main advantage of the flexible storage container is its cost over a 10-year period when compared with conventional storage. The flexible containers have a total 10-year cost of less than half of the cost of conventional steel storage tanks.

Another advantage is ease of maintenance. Unlike conventional storage, a damaged flexible container can be repaired by the operators and placed back on stream in 5 hours.

Repairs are made by patching the damaged area with a patch made of the original material, using a suitable adhesive. The repaired area is then as strong as, if not stronger than, the rest of the container.

Aside from the factors already mentioned, the flexible storage container is not clearly superior to conventional methods of storage, but it can do the same job for half the cost.

It is designed to withstand the elements and does so readily. It can be designed to withstand winds of 125 mph but not the objects such winds would carry. For this reason, the containers are designed for 75-mph winds and are lashed down with nylon mesh nets during hurricanes. Since hurricanes are now located days in advance, the half hour it takes to secure each container is ample.

Loss of helium through permeation is approximately 1000 SCF (10 lb.) per year per container. This is 1/360,000 of the volume available per year per container.

On page 23 a picture of one of the helium storage containers in use at Lewis Research Center is shown. This container is 90 feet in diameter and can contain 200,000 SCF (2000 lb.) of helium. The containers to be used in the helium collection and purification system would be approximately 150 feet in diameter and contain approximately 877,500 SCF (8775 lb.) each.

Some of the prominent features shown in the picture on page 23 are:

1. The triangular calibrated vent on the top of the hemisphere. This vent allows air to escape fast enough to keep the container from overpressurizing (there is also a relief valve), yet slow enough to allow the container to retain its shape.

2. The inflation blower at the base of the container to the right of the two men in the picture.

3. The 12-inch plastic porthole partially hidden by one of the fence posts.

4. The fence to protect the containers from personnel vehicles, etc.

NASA
C-58094

Coated-Nylon Air-Supported Helium Storage Container
Lewis Research Center

PART V

SATURN V HELIUM RECOVERY SYSTEMS

A. DESCRIPTION

This study considers seven systems for the recovery and repurification of helium used in the launch preparation and checkout of the Saturn V vehicle. These seven systems are described below:

1. Alternate 1 (Figure 9).

   a. Fixed helium purification plant using cycle IV and located at the CCF.

   b. Fixed low-pressure storage of 1 million SCF (10,000 lb.) at the VAB and 2.5 million SCF (25,000 lb.) at each pad. (All blowers included with storage.)

   c. 15-psia piping to the purification plant - 3-inch IPS from the VAB and 6-inch IPS from each pad.

2. Alternate 2 (Figure 10).

   a. Fixed helium purification plant using cycle IV and located at the CCF.

   b. Fixed low-pressure storage of 1 million SCF (10,000 lb.) at the VAB and 2.5 million SCF (25,000 lb.) at each pad. (All blowers included with storage.)

   c. 6,000-psig trailers to transport contaminated helium to the helium purification plant.

   d. Portable 0- to 6,000-psi compressor to compress the gas into trailers.

3. Alternate 3 (Figure 11).

   a. Mobile helium purification plant using cycle IV and capable of using a prepared location at the VAB and at each pad.

   b. Fixed low-pressure storage of 1 million SCF (10,000 lb.) at the VAB and 2.5 million SCF (25,000 lb.) at each pad. (All blowers included with storage.)

   c. 225-psia piping to the CCF - 1-inch IPS from the VAB, 1-1/2-inch IPS from each pad.

4. Alternate 4 (Figure 12).

   a. Mobile helium purification plant using cycle IV and capable of using prepared locations at the VAB and at each pad.

   b. Fixed low-pressure storage of 1 million SCF (10,000 lb.) at the VAB and 2.5 million SCF (25,000 lb.) at each pad. (All blowers included with storage.)

   c. Portable 0- to 6,000-psig compressor to compress the pure helium into 6,000-psig trailers for transportation to the CCF.

   d. 6,000-psig trailers for pure helium.

5. Alternate 5 (Figure 13).

   a. Fixed helium purification plant using cycle IV and located at the CCF.

   b. Mobile low-pressure storage for collecting the contaminated helium at the VAB and at each pad and transporting it to the plant at the CCF.

6. Alternate 6 (Figure 14).

   a. Mobile helium purification plant using cycle IV and capable of using prepared locations at the VAB and at each pad.

   b. Fixed low-pressure storage of 1 million SCF (10,000 lb.) at the VAB and 2.5 million SCF (25,000 lb.) at each pad. (All blowers included with storage.)

   c. Portable 0- to 6,000-psig compressor for charging the storage banks at the VAB and at each pad.

   d. High-pressure flexible piping from the compressor to the storage banks.

7. Alternate 7 (Figure 15).

   a. Fixed helium purification plant using cycle IV and located at the CCF.

   b. Fixed low-pressure storage located at the CCF of 2.5 million SCF (25,000 lb.). (All blowers included with storage.)

   c. Low-pressure pipeline to storage at CCF - 10-inch IPS from each pad and 4-inch IPS from the VAB.

d. 1,200-SCFH blower at the VAB and at each pad.

e. Portable 500,000-SCFH blower for use at the VAB or at each pad during large volume purges.

B. DISCUSSION

1. Alternate 1 (see Figure 9).

The helium used at the VAB and at each pad is collected into the low-pressure storage containers by low-pressure, large-volume blowers included in the storage system. These blowers have recycle systems to prevent their drawing a vacuum on the helium source. The storage is sized to contain the excess over the purification plant's normal feed rate, which is supplied to the purification plant through 15-psia pipelines. The plant processes the contaminated helium at a constant rate of 46 pounds per hour, 24 hours per day, 7 days per week. The purified helium leaves the plant at 225 psia to enter one of the CCF compressors for distribution.

2. Alternate 2 (see Figure 10).

The helium used at the VAB and at each pad is collected into the low-pressure storage containers by low-pressure, large-volume blowers included in the storage system. These blowers have recycle systems. The storage is sized to contain the excess over the purification plant's normal feed rate, which is supplied to the plant by 6,000-psig trailers. A portable 0- to 6,000-psig compressor is used to fill the trailers at a slightly greater rate than the plant's 46 pounds per hour.

3. Alternate 3 (see Figure 11).

Contaminated helium is collected into low-pressure storage containers at the VAB and at each pad by low-pressure, large-volume blowers included in the storage system. The purification plant is fully mobile, though dependent on power and water at prepared locations. Processing helium at 46 pounds per hour, the plant sends the product through a pipeline at 225 psia to the CCF for distribution.

4. Alternate 4 (see Figure 12).

Contaminated helium is collected into low-pressure storage containers at the VAB and at each pad by low-pressure, large-volume blowers included in the storage system. The gas is then purified by a mobile purification plant at 46 pounds per hour. As the pure helium leaves the purification plant, it is picked up by a portable compressor at atmospheric pressure and compressed into trailers at 6,000 psig. The trailers are used to deliver the gas to the CCF for distribution.

5. Alternate 5 (see Figure 13).

Contaminated helium is collected into low-pressure storage containers at the VAB and at each pad by low-pressure, large-volume blowers included in the storage system. The storage containers are large bags resembling airships. The system would include a self-ballasting device to offset the lift produced as the bag fills with helium. When the bag is filled, it is towed to the tiedown site near the plant, where it is emptied and where the helium is purified and delivered to the CCF for distribution.

6. Alternate 6 (see Figure 14).

The helium, after use, is collected into low-pressure storage containers at the VAB and at each pad using blowers which are a part of the storage system. The contaminated helium is processed by the mobile purification plant at 46 pounds per hour. The mobile purification plant can operate at any site that has power and water available. After purification, the helium is compressed into the pure storage container at the VAB or at each pad by a portable 0- 6,000-psig compressor. The CCF is bypassed in this alternate.

7. Alternate 7 (see Figure 15).

The helium is transported to the CCF through a 4-inch IPS pipeline from the VAB and through a 10-inch IPS pipeline from each pad. A small 1,200-SCFH blower is permanently installed at each use site. During the operations which require large purges, a portable 500,000-SCFH blower is brought on stream. This blower has a recycle system to allow it to be started prior to the actual purge. The purification plant is located near the storage container at the CCF and processes the stored contaminated helium. The CCF is used to distribute the purified product.

C. COMPARATIVE COST ESTIMATES

The estimates listed for the helium purification systems, composed of purification plant, gas transportation equipment, and storage, were developed on a comparative basis. Items common to all systems are not necessarily included in these estimates. The estimates are based on the preliminary data of Phase I of this study. They are composed of three main parts: investment, fixed annual operating costs, and variable operating costs. For each point of comparison, the evaluation of these alternates was made over a range of launch rates varying from one launch per year to six launches per year (series operation). This range was picked for two reasons: (1) A common basis is established for comparison of these alternate systems, and (2) in this range (one to six launches per year), each of these systems becomes profitable.

A comparison of all alternate recovery systems evaluated appears in Table X.

1. Alternate 1

a. Investment

(1) Storage (flexible coated-nylon container)		
VAB - 1 million SCF (10,000 lb.)		$ 345,000
Pad - 2.5 million SCF (25,000 lb.)		862,500
(2) Purification Plant - Cycle IV		407,165
(3) Piping		
VAB to CCF - 5,000' of 3" IPS		28,750
Pad to CCF - 14,000' of 6" IPS		169,100
	Total	$1,812,515
Annual Capital Charge (10-Year Amortization)		$ 181,252

b. Fixed Annual Operating Costs

(1) Labor*		$ 70,080
(2) Chemicals and Lubricants $3/HP/Year x 33 HP		99
(3) Maintenance at 1.5% of Investment		26,929
	Subtotal	$ 97,108
(4) NASA G&A at 10% of Operating Cost		9,711
	Total	$ 106,819

c. Variable Annual Operating Costs

(1)	Power	VAB - 35 KW, Pad - 21 KW	$ 535
(2)	Water	VAB - 630 GPH, Pad - 1040 GPH	110
(3)	LIN	VAB - 20 GPH, Pad - 20 GPH	3,828

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk

c. Variable Annual Operating Costs (Continued)

(4)	LOX Pad only - 290 SCFH		$ 242
		Subtotal	$ 4,715
(5)	NASA G&A at 10% of Operating Costs		472
		Total/Launch	$ 5,187

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$181,252	$106,819	$ 5,187	$293,258	52,114 lb.	$ 5.63
2	181,252	106,819	10,374	298,445	104,228	2.86
3	181,252	106,819	15,561	303,632	156,342	1.94
4	181,252	106,819	20,748	308,819	208,456	1.48
5	181,252	106,819	25,935	314,006	260,570	1.21
6	181,252	106,819	31,122	319,193	312,684	1.02

2. Alternate 2

a. Investment

(1)	Storage (flexible coated-nylon container)	
	VAB - 1 million SCF (10,000 lb.)	$ 345,000
	Pad - 2.5 million SCF (25,000 lb.)	862,500
(2)	Purification Plant - Cycle IV	407,165
(3)	Helium Trailers - 4 ea. (550 cu. ft. water volume)	284,680
(4)	Portable Helium Compressor - 0 to 6,000 psi	84,700
	Total	$ 1,984,045
	Annual Capital Charge (10-Year Amortization)	$ 198,405

b. Fixed Annual Operating Costs

(1)	Labor*		$ 92,845
(2)	Chemicals and Lubricants $3/HP/Year x 33 HP		99
(3)	Maintenance at 1.5% of Investment		29,502
		Subtotal	$ 122,446
(4)	NASA G&A at 10% of Operating Costs		12,244
		Total	$ 134,690

c. Variable Annual Operating Costs

(1)	Power	VAB - 35 KW, Pad - 21 KW		$ 535
(2)	Water	VAB - 630 GPH, Pad - 1040 GPH		110
(3)	LIN	VAB - 20 GPH, Pad - 20 GPH		3,828
(4)	LOX	Pad only - 290 SCFH		242
(5)	Portable Compressor Costs			200
			Subtotal	$ 4,915
(6)	NASA G&A at 10% of Operating Costs			492
			Total/Launch	$ 5,407

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk
1 Compressor Operator
2 Truck Drivers

d. Trend Tabulations

No. Of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$198,405	$134,690	$ 5,407	$338,502	52,114 lb.	$ 6.50
2	198,405	134,690	10,814	343,909	104,228	3.30
3	198,405	134,690	16,221	349,316	156,342	2.23
4	198,405	134,690	21,628	354,723	208,456	1.70
5	198,405	134,690	27,035	360,130	260,570	1.38
6	198,405	134,690	32,442	365,537	312,684	1.17

3. Alternate 3

a. Investment

(1) Storage (flexible coated-nylon container)	
VAB - 1 million SCF (10,000 lb.)	$ 345,000
Pad - 2.5 million SCF (25,000 lb.)	862,500
(2) Purification Plant - Cycle IV - Mobile	438,996
(3) Piping	
VAB to CCF - 5,000' of 1" IPS	17,250
Pad to CCF - 14,000' of 1-1/2" IPS	64,400
Total	$1,728,146
Annual Capital Charge (10-Year Amortization)	$ 172,815

b. Fixed Annual Operating Costs

(1) Labor*	$ 70,080
(2) Chemicals and Lubricants $3/HP/Year x 33 HP	99

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk

b. Fixed Annual Operating Costs (Continued)

(3) Maintenance at 1.5% of Investment		$ 25,922
	Subtotal	$ 96,101
(4) NASA G&A at 10% of Operating Costs		9,610
	Total	$ 105,711

c. Variable Annual Operating Costs

(1)	Power	VAB - 35 KW, Pad - 21 KW		$ 535
(2)	Water	VAB - 630 GPH, Pad - 1040 GPH		110
(3)	LIN	VAB - 20 GPH, Pad - 20 GPH		3,828
(4)	LOX	Pad only - 290 SCFH		242
(5)	Equipment Moving Costs			80
			Subtotal	$ 4,795
(6)	NASA G&A at 10% of Operating Costs			480
			Total/Launch	$ 5,275

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$172,815	$105,711	$ 5,275	$283,801	52,114 lb	$ 5.45
2	172,815	105,711	10,550	289,076	104,228	2.77
3	172,815	105,711	15,825	294,351	156,342	1.88
4	172,815	105,711	21,100	299,626	208,456	1.44
5	172,815	105,711	26,375	304,901	260,570	1.17
6	172,815	105,711	31,650	310,176	312,684	.99

4. Alternate 4

Alternate 4 involves the purification of helium at the location of its use. The purified helium is then to be compressed into trailers at 6,000 psi for delivery to the compressor-converter facility (CCF), where the helium would be introduced into the system by t. CCF compressors at 6,000 psi. Using 6,000-psi trailers, the gas must be compressed to a maximum of 6,000 psi for filling. Since the storage at the VAB and at the pad is at 6,000 psi, it is simpler to compress the pure helium directly into the appropriate storage.

Since this method is presented as Alternate 6, Alternate 4 can be eliminated in favor of Alternate 6.

5. Alternate 5

Alternate 5 involves the use of a fixed purification plant at the CCF along with mobile storage units at the VAB and at each of the pads. These mobile storage units would be filled at the helium use sites, then transported to the purification plant to be emptied. Two concepts of mobile storage were investigated. The first concept was to use an airship-type flexible container, which could be towed behind a vehicle to the purification plant to be emptied, then carried on a truck back to the collection point for refilling. The second concept originated at the Phase II Report Presentation as part of a request for further study. It consisted of a fixed flexible storage container mounted on a platform that could be transported on the existing crawlerway.

a. When the mobile storage-airship design was discussed with Goodyear Tire and Rubber Company personnel, they would not recommend it for the following reasons:

(1) The storage container would in reality be an airship, thus making all of an airship's ground support equipment necessary for use with the storage container.

(2) A system would have to be developed to enable the storage system to be self-ballasting while being filled to prevent its lift from tearing the bag loose from its mooring.

(3) The storage system would have to be free to rotate with changes in wind direction while being filled to enable the bag to expose its smallest cross-sectional area to the wind.

(4) All systems listed above require development, since they are more than simple modifications of present handling systems.

(5) In their opinion, the above system would be more expensive than the fixed storage system with the pipeline included and would require a development contract.

For these reasons it was decided to eliminate this concept from further consideration.

b. The second concept, using the fixed storage container modified for transportation and provided with a means of locomotion compatible with the existing crawlerway, was evaluated. The approximate cost of this total system is listed below in the appropriate categories:

(1) Crawlerway extension and parking areas. Approximately 7000 feet of additional roadway is required. This would have an area of 280,000 square feet. Using the supplied construction rate of $1/sq. ft. for this service road construction, two 20-foot-wide lanes 7000 feet long would cost $280,000 and would provide enough parking areas and access to them at the VAB, at the CCF, and at each of the pads.

(2) Framework. The smallest framework possible would require an envelope of a square 120 feet on a side. A typical case would be composed of six double-bogie, dual-wheel axles mounted on three 90-foot bridge trusses to span the crawlerway and provide an even distribution of weight on the crawlerway. This framework of at least 185,000 pounds could be constructed of carbon steel for about $.20/lb. or a total of $37,000.

(3) Wheels and axles. The six dual-wheel, double-bogie axle sets would cost approximately $3000 each or $18,000 total. The wheels, complete with tires, would cost $100 each for a total of $4800.

(4) Portable generating equipment and miscellaneous. Twin portable generating units would cost $2000. Miscellaneous equipment might cost another $3000.

(5) Design engineering. Engineering would be at least 15 percent of the equipment cost or $9,630 for the first carrier and $5000 for each additional carrier.

(6) Locomotion. To provide locomotion, two tractors of the type used to move heavy aircraft would be required. The two vehicles would cost at least $50,000.

(7) Blowers and instrumentation. Each helium collection site would require the same helium blower capacity as for permanent storage, but since this item is common to all alternates, it has not been considered in Phase II. It will be included in Phase III work. The cost of these blowers has not been included in any alternate of Phase II.

The total costs would then be as follows:

Crawlerway Extension and Parking Areas	$ 322,000
Storage Carriers (7 at $64,800 each)	453,600
Storage Carrier Engineering	39,630
Transporters (2 vehicles)	50,000
Subtotal	$ 865,230

Storage Containers and Purification Plant	$1,614,665
Total	$2,479,895

This is $911,050 higher in cost than Alternate 7.

It is felt that the mobile storage concept as described in Alternate 5 is economically unjustified, and is therefore eliminated from further consideration in this study.

6. Alternate 6

a. Investment

(1)	Storage (flexible coated-nylon container)	
	VAB - 1 million SCF (10,000 lb.)	$ 345,000
	Pad - 2.5 million SCF (25,000 lb.)	862,500
(2)	Purification Plant - Cycle IV - Mobile	438,996
(3)	Portable Helium Compressor	84,700
(4)	Piping to Pure Helium Storage - 4000 ft. Flexible	46,000
	Total	$1,777,196
	Annual Capital Charge (10-Year Amortization)	$ 177,720

b. Fixed Annual Operating Costs

(1)	Labor*	$ 77,855
(2)	Chemicals and Lubricants $3/HP/Year x 50 HP	150
(3)	Maintenance at 1.5% of Investment	26,658
	Subtotal	$ 104,663

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk
1 Compressor Operator

b. Fixed Annual Operating Costs (Continued)

(4) NASA G&A at 10% of Operating Costs		$ 10,466
	Total	$ 115,129

c. Variable Annual Operating Costs

(1) Power	VAB - 35 KW, Pad - 21 KW		$ 535
(2) Water	VAB - 630 GPH, Pad - 1040 GPH		110
(3) LIN	VAB - 20 GPH, Pad - 20 GPH		3,828
(4) LOX	Pad only - 290 SCFH		242
(5) Equipment Moving Costs			80
(6) Compressor Operating Costs			200
		Subtotal	$ 4,995
(7) NASA G&A at 10% of Operating Costs			500
		Total/Launch	$ 5,495

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$177,720	$115,129	$ 5,495	$298,344	52,114 lb.	$ 5.73
2	177,720	115,129	10,990	303,839	104,228	2.92
3	177,720	115,129	16,485	309,334	156,342	1.98
4	177,720	115,129	21,980	314,829	208,456	1.51
5	177,720	115,129	27,475	320,324	260,570	1.23
6	177,720	115,129	32,970	325,819	312,684	1.04

7. Alternate 7

a. Investment

(1) Storage (flexible coated-nylon container)

CCF - 2.5 million SCF (25,000 lb.) $ 862,500

(2) Purification Plant - Cycle IV 407,165

a. Investment (Continued)

(3) Piping

VAB to CCF - 5,000' of 4" IPS		$ 40,250
Pad to CCF - 14,000' of 10" IPS		196,000

(4) Blowers

VAB - 1200 SCFH - 3/4 HP		430
Pad - 1200 SCFH - 1-1/2 HP		500
Portable - 500,000 SCFH - 780 HP		62,000
	Total	$1,568,845
Annual Capital Charge (10-Year Amortization)		$ 156,885

b. Fixed Annual Operating Costs

(1) Labor*		$ 77,855
(2) Chemicals and Lubricants $3/HP/Year x 284 HP		852
(3) Maintenance at 1.5% of Investment		23,533
	Subtotal	$ 102,240
(4) NASA G&A at 10% of Operating Costs		10,224
	Total	$ 112,464

c. Variable Annual Operating Costs

(1) Power	VAB - 21 KW, Pad - 21 KW	$ 678
(2) Water	VAB - 630 GPH, Pad - 1040 GPH	110
(3) LIN	VAB - 20 GPH, Pad - 20 GPH	3,828

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk
1 Compressor Operator

c. Variable Annual Operating Costs (Continued)

(4)	LOX Pad only - 290 SCFH		$ 242
		Subtotal	$ 4,858
(5)	NASA G&A at 10% of Operating Costs		486
		Total/Launch	$ 5,344

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$156,885	$112,464	$ 5,344	$274,693	52,114 lb.	$ 5.27
2	156,885	112,464	10,688	280,037	104,228	2.69
3	156,885	112,464	16,032	285,381	156,342	1.83
4	156,885	112,464	21,376	290,725	208,456	1.40
5	156,885	112,464	26,720	296,069	260,570	1.14
6	156,885	112,464	32,064	301,413	312,684	.96

D. CONCLUSIONS

The most economical alternate is Alternate 7. However, it should be noted that the unit costs of all of the alternates are close and that in all cases the potential savings are great. The cost of processing the helium is approximately $1.00 per lb. and the cost of new helium shipped in is $4.50 per lb. The savings over the course of the Saturn V program will be between 10 and 50 million dollars, depending almost entirely on the number of vehicles to be launched during the next 10 years.

PART VI

SATURN IB HELIUM RECOVERY SYSTEMS

A. DESCRIPTION

An evaluation of the different combinations and variations possible for a helium recovery system for the Saturn V vehicles at MILA showed the most likely system to be composed of low-pressure storage, a helium purification plant utilizing cycle IV, and low-pressure piping. This system was selected for use in investigating the recovery of helium from Complex 34 and Complex 37 as used in the checkout of the Saturn IB vehicle.

It was decided to investigate four alternates for this system which differ only in the location of the purification plant and in the method of transporting the impure gas to it. These alternates are described below:

1. Alternate A (Figure 18).

   a. Fixed low-pressure storage of 700,000 SCF (7000 lb.) located at this area's CCF.

   b. Fixed helium purification plant using cycle IV and located at this area's CCF.

   c. Low-pressure piping from each pad to the storage at this area's CCF.

2. Alternate B (Figure 19).

   a. Fixed low-pressure storage of 700,000 SCF (7000 lb.) located at this area's CCF.

   b. 6,000-psig trailers to transport the contaminated helium to Complex 39 for purification.

   c. Fixed 0- to 6,000-psig compressor to fill trailers.

   d. Low-pressure piping from each pad to the storage at this area's CCF.

3. Alternate C (Figure 20).

   a. Fixed low-pressure storage of 700,000 SCF (7000 lb.) located at this area's CCF.

   b. 30,000 feet of 1-1/2-inch IPS piping from storage to Complex 39 for purification.

c. Blower to move contaminated helium through pipeline.

d. Low-pressure piping from each pad to the storage at this area's CCF.

4. Alternate D (Figure 21).

a. Fixed low-pressure storage of 1,000,000 SCF (10,000 lb.) located at this area's CCF.

b. Mobile helium purification plant for use part-time at a prepared site near this area's CCF.

c. Low-pressure piping from each pad to the storage at this area's CCF.

B. DISCUSSION

1. Alternate A (see Figure 18).

The contaminated helium is piped from its place of use at either Complex 34 or Complex 37 to a low-pressure storage container at this area's CCF. The gas is then purified in a fixed purification plant, using cycle IV, and made available for reuse.

2. Alternate B (see Figure 19).

The contaminated helium is piped from its place of use to a low-pressure storage container at this area's CCF. The gas is then compressed into 6,000-psi trailers for transportation to the contaminated storage at Complex 39 for processing in that area. Four trailers will be required for this transportation.

3. Alternate C (see Figure 20).

The contaminated helium is piped from its place of use to a low-pressure storage container at this area's CCF. From this storage, the gas is moved at a steady rate through a low-pressure pipeline to the contaminated storage at Complex 39 for processing in the purification plant there.

4. Alternate D (see Figure 21).

The contaminated helium is piped into a low-pressure storage container located at this area's CCF. A mobile purification plant purifies the stored gas between its operations at Complex 39. The purified gas is then introduced into the Saturn V system by the compressors in that CCF.

C. COMPARATIVE COST ESTIMATES

The estimates listed below as Alternates A, B, C and D were developed on a comparative basis. Items common to all alternates are not necessarily included in this estimate.

The estimates are composed of three main parts; investment, fixed annual operating costs, and variable annual operating costs.

For ease of evaluation, the comparison of these alternates was made over a range of launch rates varying from one launch per year to six launches per year. This range was picked for two reasons: (1) to establish a common basis for the comparison of these alternate systems, and (2) because in this range (one to six launches per year), each of these systems becomes profitable.

A comparison of all alternate recovery systems is summarized in Table XI.

1. Alternate A

a. Investment

(1)	Storage - 700,000 SCF (7000 lb.)	$ 241,500
(2)	Helium Purification Plant - Cycle IV	407,165
(3)	Blower - 2 each	3,500
(4)	Pipeline	
	34 to CCF - 4100' of 5" IPS	40,077
	37 to CCF - 4300' of 5" IPS	42,033
	Total	$ 734,275
	Annual Capital Charge (10-Year Amortization)	$ 73,428

b. Fixed Annual Operating Costs

(1)	Labor*	$ 70,080
(2)	Chemicals and Lubricants $3/HP/Year x 33 HP	99

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk

b. Fixed Annual Operating Costs (Continued)

(3) Maintenance at 1.5% of Investment		$ 11,014
	Subtotal	$ 81,193
(4) NASA G&A at 10% of Operating Costs		8,119
	Total	$ 89,312

c. Variable Annual Operating Costs

(1) Power	21 KW		$ 329
(2) Water	1040 GPH		48
(3) LIN	20 GPH		2,041
(4) LOX	2.6 SCFH		270
		Subtotal	$ 2,688
(5) NASA G&A at 10% of Operating Costs			269
		Total/Launch	$ 2,957

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$73,428	$89,312	$ 2,957	$162,740	12,936 lb.	$12.58
2	73,428	89,312	5,914	165,697	25,872	6.40
3	73,428	89,312	8,871	168,654	38,808	4.35
4	73,428	89,312	11,828	171,611	51,744	3.32
5	73,428	89,312	14,785	174,568	64,680	2.70
6	73,428	89,312	17,742	177,525	77,616	2.29

2. Alternate B

a. Investment

(1) Storage - 700,000 SCF (7000 lb.)	$ 241,500
(2) Compressor - 0 to 6,000 psig - Portable	84,700

(3)	Trailers - 4 each		
	500 cubic feet water volume - 6,000 psig	$	284,680
(4)	Blowers - 2 each		3,500
(5)	Pipeline		
	34 to CCF - 4100' of 5" IPS		40,077
	37 to CCF - 4300' of 5" IPS		42,033
(6)	Helium Purification Plant Shared with MILA		76,750
	Total	$	773,240
	Annual Capital Charge (10-Year Amortization)	$	77,324

b. Fixed Annual Operating Costs

(1)	Labor*	$	59,460
(2)	Chemicals and Lubricants $3/HP/Year x 20 HP		60
(3)	Maintenance at 1.5% of Investment		11,600
	Subtotal	$	71,120
(4)	NASA G&A at 10% of Operating Costs		7,112
	Total	$	78,232

c. Variable Annual Operating Costs

(1)	Power 15 KW	$	200
(2)	Water		30
(3)	Percentage share of MILA purification plant costs		2,140
	Subtotal	$	2,370

*Labor crew consisting of:
1 Assistant Superintendent
4 Operators
2 Truck Drivers

c. Variable Annual Operating Costs (Continued)

(4) NASA G&A at 10% of Operating Costs	$	237
Total/Launch	$	2,607

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$77,324	$78,232	$ 2,607	$158,163	12,936 lb.	$12.23
2	77,324	78,232	5,214	160,077	25,872	6.21
3	77,324	78,232	7,821	163,377	38,808	4.21
4	77,324	78,232	10,428	165,984	51,744	3.21
5	77,324	78,232	13,035	168,591	64,680	2.61
6	77,324	78,232	15,642	171,198	77,616	2.21

3. Alternate C

a. Investment

(1) Storage - 700,000 SCF (7000 lb.)	$	241,500
(2) Pipelines		
34 to CCF - 4100' of 5" IPS		40,077
37 to CCF - 4300' of 5" IPS		42,033
CCF to MILA - 30,000' of 1-1/2" IPS		120,000
(3) Blowers		
34 and 37 - 2 each		3,500
CCF		2,000
(4) Helium Purification Plant Shared with MILA		76,750
Total	$	525,860
Annual Capital Charges (10-Year Amortization)	$	52,586

b. Fixed Annual Operating Costs

(1)	Labor*		$ 43,000
(2)	Chemicals and Lubricants $3/HP/Year x 30		90
(3)	Maintenance at 1.5% of Investment		7,888
		Subtotal	$ 50,978
(4)	NASA G&A at 10% of Operating Costs		5,098
		Total	$ 56,076

c. Variable Annual Operating Costs

(1)	Power - 22 KW		$ 263
(2)	Water		37
(3)	Percentage share of MILA purification plant costs		2,140
		Subtotal	$ 2,440
(4)	NASA G&A at 10% of Operating Costs		244
		Total/Launch	$ 2,684

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$52,586	$56,076	$ 2,684	$111,346	12,936 lb.	$ 8.61
2	52,586	56,076	5,368	114,030	25,872	4.41
3	52,586	56,076	8,052	116,714	38,808	3.01
4	52,586	56,076	10,736	119,398	51,744	2.31
5	52,586	56,076	13,420	122,082	64,680	1.89
6	52,586	56,076	16,104	124,766	77,616	1.61

*Labor crew consisting of:
1 Assistant Superintendent
4 Operators

4. Alternate D

a. Investment

(1)	Storage - 1,000,000 SCF (10,000 lb.)	$ 345,000
(2)	Blower at 34 and 37 - 2 each	3,500
(3)	Pipeline	
	37 to CCF - 4300' of 5" IPS	42,033
	34 to CCF - 4100' of 5" IPS	40,077
(4)	Mobile Helium Purification Plant Shared with MILA	85,000
	Total	$ 515,610
	Annual Capital Charge (10-Year Amortization)	$ 51,561

b. Fixed Annual Operating Costs

(1)	Labor*	$ 70,080
(2)	Chemicals and Lubricants $3/HP/Year x 33 HP	99
(3)	Maintenance at 1.5% of Investment	7,734
	Subtotal	$ 77,913
(4)	NASA G&A at 10% of Operating Costs	7,791
	Total	$ 85,704

c. Variable Annual Operating Costs

(1)	Power	$ 330
(2)	Water	48
(3)	LIN	2,041

*Labor crew consisting of:
1 Superintendent
1 Assistant Superintendent
4 Operators
1 Maintenance Man
1 Clerk

c. Variable Annual Operating Costs (Continued)

(4) LOX		$ 261
	Subtotal	$ 2,680
(5) NASA G&A at 10% of Operating Costs		268
	Total/Launch	$ 2,948

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$51,561	$85,704	$ 2,948	$140,213	12,936 lb.	$10.84
2	51,561	85,704	5,896	143,161	25,872	5.53
3	51,561	85,704	8,844	146,109	38,808	3.77
4	51,561	85,704	11,792	149,057	51,744	2.88
5	51,561	85,704	14,740	152,005	64,680	2.35
6	51,561	85,704	17,688	154,953	77,616	2.00

D. CONCLUSIONS

The most economical alternate is Alternate C, and, although the possible savings to be obtained in the Saturn IB program are not as great as those for the Saturn V program, the purification of the used helium is still desirable.

The advisability of installing a recovery system for Saturn IV alone is at best questionable. It would seem that helium recovery and reuse is dependent on the Saturn V system.

PART VII

PRELIMINARY DESIGN OF A HELIUM RECOVERY SYSTEM FOR MILA

A. GENERAL

Using the helium data presented in Part II and the conclusions arrived at during Phase II as summarized in Parts III through VI, a preliminary design was developed to obtain the most economical, safe, and operational helium recovery system for the Merritt Island Launch Area. This work included design of an optimum purification cycle, determination of optimum size for the purification plant, development of economics at various launch rates, and establishment of broad design parameters to permit final design and procurement of an operational helium recovery system. The results of this phase are summarized and discussed in the subsequent sections.

B. DESIGN OF AN OPTIMUM PROCESS CYCLE

A considerable portion of the variable operating costs for the helium purification plant is in liquid nitrogen consumption. Approximately 25% of this liquid nitrogen is used to cool the process stream directly, but about 75% is used to cool the nitrogen adsorber (08.41) during the cooldown portion of the reactivation cycle. Because all other costs, both fixed and variable, are already optimized or small, this study has focused attention on reducing the cooldown liquid nitrogen requirements to a minimum. The following sections present a summary of the results of this investigation.

1. Adsorber Cooldown Economizer Exchanger.

During adsorber cooldown, helium is circulated from the reactivation compressor (01.21) (see Figure 4) through the cooldown exchanger (08.25A & B) where it is cooled by liquid nitrogen, and then to the adsorber (08.41), where the gas cools the adsorber bed. Initially, the gas leaving the adsorber is at ambient temperature, having been warmed to this temperature in the adsorber bed. However, as the adsorber begins to cool down, the gas will return at less than ambient temperature, getting progressively colder until at the completion of cooldown, the temperature leaving will be the same as the temperature entering.

From experience on similar cycles, it has been determined that a savings of one-third of the duty on the cooldown exchanger results from providing an exchanger to recover this refrigeration for precooling the circulation gas to the cooldown exchanger. Thus, the average liquid nitrogen consumption is decreased by one-third. To evaluate this on an economic basis, the cost of the economizer exchanger must be balanced against the savings in liquid nitrogen. For the present case, if the plant operates full time, the economizer saves its price in liquid nitrogen in about 4 months; from another point of view, for a 5-year payout the plant must operate at capacity only about 7% of the time. Clearly the addition is economically justified, and it is shown as the adsorber cooldown economizer exchanger (08.27) in Figure 24.

2. <u>Operating Pressure Considerations</u>.

The capacity of charcoal for adsorbing nitrogen is a function of, among other things, the partial pressure of the nitrogen in the process stream. Increasing the total pressure of the gas in the bed raises the partial pressure of the contained nitrogen. At this higher partial pressure, the charcoal has a higher capacity for nitrogen, and thus less charcoal is required to remove the same amount of nitrogen from the process stream. Having less total charcoal to cool means smaller liquid nitrogen requirement for cooldown. Another factor enters, however, because the liquid nitrogen must also cool the vessel in which the charcoal is contained, and with higher head pressure a thicker wall is required, i.e., a heavier vessel for the same overall requirements. Thus the mass of charcoal goes down but the mass of metal goes up for increased head pressure. Calculations for six pressure levels between 150 and 3000 psig indicated that the lowest pressure level, 150 psia, would give the lowest total cooldown requirements, in addition to saving on compressor investment and operating cost.

3. <u>Increasing Cryogenic Separation of Nitrogen</u>.

Another way to reduce the amount of charcoal required, and thus reduce the amount of required cooldown liquid nitrogen, is to reduce the total amount of nitrogen which is contained in the process stream at the adsorber inlet. This can be accomplished by decreasing the temperature of the process stream to the liquid nitrogen separator (07.81) (see Figure 4). By cooling the process stream to -318°F, 92% of the nitrogen is removed in the liquid separator. By cooling to -338°F, 97.5% is removed. This is about the lowest practical temperature, since the nitrogen triple-point temperature is -346°F. This temperature can be achieved by creating a partial vacuum in the nitrogen reboiler (05.22 of Figure 4). Since an economic analysis gives a payout period of less than a year, the addition is justified.

4. Other Considerations.

Charcoal capacity data which have been used in this study are from tests on standard commercial materials. Although occasionally a company may develop a slightly higher capacity charcoal, the increase is relatively small and, for the purpose of this study, insignificant. At the time the plant is to be fabricated, the highest capacity charcoal available at that time, having the other necessary characteristics, would be obtained for the adsorber.

The possibility of using an insert in the adsorber to insulate the vessel thermally from the charcoal bed has also been considered. This would reduce the cooldown load due to the walls of the vessel. Air Products and Chemicals experience with inserts of this type has been that they are not effective, and in fact cause operating problems which make them unacceptable. For these reasons, inserts are not recommended.

The main compressor previously considered was oil lubricated and consequently required oil-removal equipment in the process stream. Because the head pressure is relatively low, a nonlubricated reciprocating compressor provides definite advantages for this application. Although maintenance costs are higher than for a lubricated compressor, the oil-removal equipment is not needed. The major advantage, however, is in eliminating the gradual poisoning of the deoxo beds which occurs with the slight amount of oil carryover from the oil removal equipment. When poisoned, a deoxo bed loses its effectiveness and must be replaced.

C. DETERMINING OPTIMUM STORAGE PLANT CAPACITIES

Since the cost of storage is a significant portion of the total cost of a purification system, analysis of minimum storage requirements, or optimum ratio of storage to plant capacity, is justifiable from an economic viewpoint. Results of these studies are presented in the following paragraphs:

1. Peak Capture.

The projected usage pattern for helium indicates that the combination of high usage rates and short usage times (e.g., P.U. purges) results in several peaks on a plot of "total helium used" versus "operation day." The capture of these peaks requires storage capacity considerably greater than that required for the average usage rates. By comparing the cost of adding a single cubic foot of storage to the cost of venting (and replacing) a cubic foot of helium, it was determined that using the additional storage only 10 times would justify its cost. With a payout period of 5 years, the added cubic foot of storage would have to be used on the average of twice a year to be economically justified. It is concluded, therefore, that storage should be sized to capture each complete peak, since predicted minimum vehicle rates are greater than two per year.

2. Ambient Temperature.

Since a rise in temperature of a gas at a fixed pressure will cause an increase in the volume of the gas, it is necessary to determine an optimum design temperature for storage. Published weather data indicate that ambient temperature will be 72°F or less for 50% of the year[1] and 85°F or less for 85% of the summer months[2]. Using these probability data together with trade-off costs of storage and venting, an optimum design temperature of 75°F was determined.

3. Plant Storage Operating Lines.

Another factor which affects the size of storage is plant capacity, or the rate at which the helium is purified. Minimum plant capacity is that which will purify the total gas used in the maximum time available. This will result in a maximum storage value. Increasing plant capacity will reduce the storage required, so that if plant capacity becomes large (and versatile) enough to process the gas as rapidly as it is being used in any operation, no storage would be required at all. For each size plant, given a particular usage pattern, there is a minimum storage volume and thus a total dollar investment for plant plus storage. A plot of investment cost versus plant capacity will indicate the lowest cost combination.

To determine the variation of storage with plant capacity, a graphical construction method was used. A typical calculation is shown in Figure 26. The "cumulative use" line is a plot of the total amount of gas entering storage from day to day as it comes from the vehicle operations. The "plant operating" lines show the total amount of helium processed by the plant from day zero to any day in question. Thus the slope of the "plant operating" line is the rate at which the helium is being processed. The minimum rate, R_M, is the total volume, V_T, divided by the total time, t_T, in which this gas is used. A larger capacity plant will have a steeper operating line (such as R_1 or R_2) and process the gas in less time.

---

[1] Evaluated Weather Data for Cooling Equipment Design, Fluor Products Co., First Edition, 1958.

[2] Tech. Paper No. 31, "Monthly Normal Temperatures, Precipitation, and Degree Days", U. S. Department of Commerce, Weather Bureau, Washington, D. C., November 1956.

The final group of lines are "storage plus plant" operating lines. From time zero until the time the plant starts up, the line remains constant at the value of storage. After the plant starts up, the amount of gas which has been processed at any time may be added to the storage volume to determine an <u>effective</u> storage volume. The storage is effectively being increased by the operation of the plant. Thus, from the time of plant startup and while the plant continues to operate, the storage line will have the same slope as the plant operating line.

To solve for a specific storage value, given a plant rate which is greater than or equal to the minimum, there are two major constraints which must be observed: (1) when the storage is empty the plant must be shut down, and (2) the storage volume must be large enough to contain all the helium used. In terms of the graphical construction, these two conditions are, respectively (1) the "plant operating" line must not cross the "cumulative use" line, and (2) the "storage plus plant" line must not cross the "cumulative use" line. The minimum storage value for a particular size plant will cause the "storage plus plant" line just to touch the "usage" line at one or more points. Examination of the graphical construction in Figure 26 shows that as the plant rate increases, the total storage decreases. Plotting the total investment, i.e., plant cost plus required storage cost, versus the plant capacity results in a graph such as that shown in the lower portion of Figure 26. The optimum plant design capacity at minimum investment can be determined in this way for each usage pattern of interest. This has been done for the various launch rates, and these optimum values of plant storage capacity have been used in the economic analysis.

4. <u>Summary</u>.

In addition to the above, the effect of two other items on storage size were considered. They are safety factor and unscheduled plant shutdown. The safety factor was evaluated by predicating the uncertainty of the values used in obtaining the "cumulative use" curve (Figure 26). It can be seen in this figure that the storage is completely full only a few times during the usage cycle, and the rest of the time it is only partially full. Thus, the safety factor can be determined from the uncertainty of the operation(s) which caused the "cumulative use" line to touch the "storage plus plant" line. In all cases, this is the P.U. gage calibration purge. Since this operation requires about an hour, it is felt that it could conceivably run over 10 to 15 minutes, on which basis a 20% safety factor was picked. Thus the storage is 1.2 times the optimum value obtained above.

Air Products and Chemicals, Inc. experience in operating similar plant indicates that a 95% plant on-stream time can be expected.

However, projected launch schedules indicate that the plant will only have to operate approximately 75% of the time. Thus, the factor of interest is the amount of scheduled operating time that the plant will be shut down for unscheduled repairs. It is felt that the plant would be shut down two to three times per year for 2-day periods, and that the rest of the maintenance can be performed during the scheduled shutdowns. It was determined above that using added storage twice a year would justify its addition on a five-year payout basis. Therefore, enough storage has been added to enable the plant to be shut down for a 2-day period without any venting of helium.

The possibility of providing a spare plant for unscheduled shutdowns, instead of adding storage was also considered. However, comparison of cost versus savings gives a 10-year payout period for this alternative.

In summary, storage is sized by taking the optimum value from the graphical construction, adding a 20% safety factor for uncertainty of purge values, adding 2 days plant capacity for unscheduled shutdowns, and allowing for an ambient temperature of 75°F.

D. PERFORMANCE CHARACTERISTICS

A numbering scheme has been used to identify the several cases of interest. For this scheme, the first digit refers to the number of Saturn V vehicles at the VAB, the second refers to the number of vehicles at the pads of Complex 39 and the third refers to the number of Saturn IB vehicles at Complex 34 and/or 37. Thus, the number 210 refers to the case in which there are two vehicles at the VAB, one at the pad and none at Complexes 34 or 37.

The sequence of parallel operations for these various vehicle densities is shown in Figure 27. For each particular vehicle, the use pattern is that shown in Figures 1 and 1A for Complexes 34 and 37, and in Figures 2 and 3 for Complex 39. Superposition of the individual vehicle use patterns from these figures according to the sequence of Figure 27 results in a cumulative use line (as in Figure 26) for each case. From each of these use lines an optimum storage plant combination has been determined by the method described in Section C.

The following subsections summarize the design conditions of the major components of the helium recovery system:

1. Helium Purification Plants.

a. Feed Gas.

Composition and Flow Rates

Case	Quantity (lb/hr)	Analysis
100	51	
200	83	90% He, 10% N_2
300	128	
110	248	
210	248	
310	279	
111	279	
211	279	80% He, 10% N_2, 10% H_2
311	310	
112	284	
212	284	
312	314	

Pressure - 0 psig
Temperature - 90°F

b. Product.

For a feed gas containing no higher concentrations of impurities than those shown above, the plants will be capable of delivering grade "A" helium at the following conditions:

Design Recovery - 99.5%
Guarantee Recovery - 97.5%
Discharge Pressure - 125 psig
Temperature - 70°F

2. Contaminated Helium Storage. (SCF-lb.)

Case	Complex 39	Complex 34 and 37
100	1,150,350 SCF (11,500 lb.)	-
200	1,150,350 SCF (11,500 lb.)	-
300	1,150,350 SCF (11,500 lb.)	-
110	2,873,510 SCF (28,735 lb.)	-
210	2,873,510 SCF (28,735 lb.)	-
310	3,534,300 SCF (35,343 lb.)	-
111	2,873,510 SCF (28,735 lb.)	1,150,350 SCF (11,500 lb.)
211	2,873,510 SCF (28,735 lb.)	1,150,350 SCF (11,500 lb.)
311	3,534,300 SCF (35,343 lb.)	1,150,350 SCF (11,500 lb.)
112	2,873,510 SCF (28,735 lb.)	1,150,350 SCF (11,500 lb.)
212	2,873,510 SCF (28,735 lb.)	1,150,350 SCF (11,500 lb.)
312	3,534,300 SCF (35,343 lb.)	1,150,350 SCF (11,500 lb.)

3. Contaminated Helium Compressors.

Complex 39: (all cases, both VAB and pad).

Flow Rate	-	5000 pounds per hour
Suction Pressure	-	0 psig
Discharge Pressure	-	6 psig

Complexes 34 and 37: (Pad to CCF).

Flow Rate	-	1550 pounds per hour
Suction Pressure	-	0 psig
Discharge Pressure	-	6 psig

Complexes 34 and 37 to Complex 39.

Flow Rate	-	27 pounds per hour
Suction Pressure	-	0 psig
Discharge Pressure	-	8 psig

4. Contaminated Helium Transmission Lines.

The line sizes are shown in Drawing SK-4-1165-55.60-1 for all cases where three pads are operating on Complex 39. For the cases where only pad A and pad B are operational, the line from pad B to the CCF becomes 14", and the line from pad A to the junction with the main line becomes 12".

E. PROCESS DESCRIPTION

The flowsheet for the final preliminary cycle design is shown in Figure 24. This cycle will purify contaminated helium collected from the VAB and the pads for Complex 39, and from Complexes 34 and 37. To accomplish this, it has been sized to purify helium which contains up to 20% nitrogen (or oxygen) and up to 12% hydrogen. Descriptions of the various stages follow:

1. Hydrogen Removal and Drying Stage.

Contaminated helium from storage passes through the filter (02.90) to remove any solid materials, and is compressed from one atmosphere to 140 psig in the main compressor (01.20). Next, the contained hydrogen is removed in three identical stages. In each stage, 2% oxygen is added to the stream. This reacts with 4% of the contained hydrogen in the deoxo converter (02.10 A, B or C). The deoxo converter contains a catalyst on an inert base, e.g., palladium on silica gel. Reaction of the hydrogen and oxygen to form water causes the temperature in the converter to rise to 900°F. This is the temperature limit of the catalyst. It is necessary, therefore, to cool the gas to 100°F in the cooler (05.70 A, B or C). This causes condensation of the water vapor which was formed by the reaction of oxygen and hydrogen. The condensed water is removed in the water separator (03.13 A, B or C), and the process stream continues to the next stage of conversion.

Control of the reaction is obtained by regulating the addition of oxygen to the process stream. The process stream leaving the last converter-cooler-separator stage (02.10C, 05.70C, and 03.13C) is continuously and automatically sampled to determine its oxygen content by an analyzer-controller (XIC). The controller regulates the oxygen valve position to maintain .05 $\pm$ .05% oxygen in the exit stream. To bring the stages on stream, assuming a gradually increasing hydrogen content, only the last stage, the automatic stage, is operating initially. As the temperature indicated on TI-4 approaches 900°F, the upper limit, the valve controlling the oxygen addition to the second stage is gradually opened, bringing the second converter (02.10B) on stream. The temperature on TI-3 is monitored and as it approaches 900°F, the final stage (02.10A) is brought on stream. The hydrogen removal unit is now working at design capacity. As the hydrogen content decreases, the opposite sequence of operations is followed, although now TI-4 will indicate the desired amount of oxygen addition to each stage.

After leaving the final water separator (03.13C), the process gas, at a temperature of 100°F, is dried to a -120°F dewpoint in the drier (03.10). The drier contains 4A molecular sieves and is regenerated on an 8-hour cycle; while one drier is on stream, the other is being regenerated. The process stream, minus hydrogen and water, continues to the nitrogen removal stage.

2. Nitrogen (and Residual Oxygen) Removal Stage.

After leaving the hydrogen removal and drying stage, the nitrogen is removed from the helium by condensing a portion of it and adsorbing the rest in an adsorber. To do this, it is necessary to cool the process stream in heat exchangers 05.21 and 05.22. From 100°F at the entrance to the warm exchanger (05.21), the process stream is cooled to -260°F against returning product stream and nitrogen vapor. From -260°F, further cooling to -338°F is obtained in the cold exchanger (05.22) by exchanging heat with the process stream leaving the liquid separator (07.81) and with nitrogen vapor and liquid. The nitrogen is on the shell side and is maintained at a pressure of 2 psia by the nitrogen vacuum pump (01.30) so that its boiling temperature is -340°F.

At the temperature of -338°F, all nitrogen in the process stream in excess of 2.5% will condense into a liquid phase. This liquid phase is removed in the nitrogen liquid separator (07.81). This liquid nitrogen is added to the nitrogen required for exchanger 05.22. The process stream, still at -338°F and containing 2.5% nitrogen, is warmed to -290°F in the upper section of exchanger 05.22.

The process stream, at -290°F, continues to the nitrogen adsorber (08.41). This adsorber, containing charcoal, adsorbs all nitrogen and oxygen down to less than 50 ppm. The Grade A helium product is then warmed to ambient temperature in the main exchanger (05.21) against incoming impure helium.

3. Drier Reactivation Cycle.

The driers (03.10) are sized so that they will require reactivation on an 8-hour cycle. The reactivation equipment is sized to perform this reactivation in a somewhat shorter time than 8 hours. Thus, two driers provide continuous service; while one is on stream, the other is being reactivated, and vice versa. The reactivation cycle is a closed cycle, and helium is the reactivation gas. Circulation is provided by the drier reactivation compressor (01.20). The helium flows from the compressor to the heater (03.17), where it is heated to 350°F. The hot gas heats the drier bed (03.10), desorbing the adsorbed water. The wet gas is cooled in the water cooler (03.11), where the water is condensed to liquid. The liquid water is removed in the water separator (03.12). The gas continues from the water separator back to the suction side of the compressor, passing first through the filter (02.91). After about 3 hours of heating, the water has been completely desorbed, and the system is subsequently purged with approximately 10 volumes of dry helium feed gas through valve 56. The purge gas is discharged to the suction side of the main compressor through valve 58. The heater is then bypassed, and cooldown of the drier to ambient temperature is accomplished in 3 hours by the same circulation route. The drier, at ambient temperature, is then ready to be placed on stream, and the other drier will be reactivated in the next 8-hour period.

4. Nitrogen Adsorber Reactivation Cycle.

As with the driers, the nitrogen adsorbers (08.41), are sized for an 8-hour on-stream period, and the reactivation equipment is sized for an 8-hour reactivation period.

Circulation of helium reactivation gas is provided by the adsorber reactivation compressor (01.22). The gas is heated to 250°F in the adsorber heater (08.43), in turn heating the adsorber (08.41) and desorbing the nitrogen. Since the gas leaving the adsorber will be at -290°F initially, but gradually warming, the gas must be warmed in the water heater (08.23) before passing to the compressor suction via the filter (02.92). After approximately 3-1/2 hours, the outlet temperature of the adsorber will reach 100°F, and the system is then depressurized and purged with 10 volumes of pure helium through valves 24 and 25. The purge gas discharges to the suction side of the main compressor through valve PIC-8. Cooldown is performed by flowing the gas through the economizer exchanger (08.27) and the cooldown exchanger (08.25). Refrigeration is provided by liquid nitrogen in the cooldown exchanger. As the adsorber cools, the gas leaving the adsorber gradually becomes colder and colder. This refrigeration is recovered in the economizer exchanger (08.27) by precooling the gas flowing to the cooldown exchanger. After approximately 2-1/2 hours, the adsorber is at an average temperature of -290°F and ready to be placed on stream.

5. Liquid Nitrogen Storage.

The liquid nitrogen storage system is a double-walled dewar with standard instrumentation provided for pressure buildup and control and for liquid transfer. The tank is filled without venting the system, and pressure is maintained in the tank automatically by means of a pressure buildup coil. A small amount of vapor is bled from the top of the tank for purging the cold box. The storage tank is sized for a 2-day supply of liquid nitrogen.

6. Cold Box Purge Systems.

The cold box is filled with perlite and requires a small purge gas stream flowing continuously to prevent atmospheric air from entering and its water vapor from freezing on the cold equipment. In the case of the cold exchanger (05.22) and the liquid separator (07.81), air and nitrogen would condense because of the low temperature involved (-340°F). These two units are isolated in an inner cold box, and a helium purge stream is provided from the product helium line. For the rest of the cold equipment, a dry nitrogen purge is provided from the liquid nitrogen storage tank. In each case, the purge flow rate is small, (on the order of 2 SCFM for the outer cold box and 0.2 SCFM for the inner cold box).

7. Startup, Shutdown and Defrost.

A normal startup of the purification plant will take approximately 4 to 6 hours, assuming that at least one drier and one adsorber are completely reactivated. Most of this time is for cooling the adsorber, using the adsorber cooldown exchanger. At the same time, the other equipment in the cold box is cooled down by circulating with the main compressor and bypassing the adsorber. After all of the equipment is at operating temperature, closed cycle operation through all of the equipment is started, and the purity of the stream at the outlet of the main exchanger is monitored. When the desired purity is reached, the plant is ready for operation.

The plant can be shut down in a relatively short time. This is done by shutting off the product valve, manually unloading the compressor, and depressurizing the system. Under certain circumstances, it may be desirable to defrost the plant rapidly, although normally heat leak would warm the plant to ambient. If shutdown occurs during the middle of a drier or adsorber reactivation cycle, it may be desirable to complete the reactivation, or it may be completed some time before the next startup.

For initial startup, or after the system has been opened for repair work, it is necessary to dry the complete system thoroughly. This can be done by directing system flow through the heater (03.17), where it is heated to about 300°F, then through all of the cold box equipment. The defrost water heater (15.50) cools the outlet gas to ambient temperature, after which the gas flows back to the suction of the main compressor. The system gas is monitored for dewpoint until it is dry.

As mentioned, it may be necessary to defrost the system rapidly after a shutdown to enable immediate repairs to be made to equipment. As with the drying operation, this can be done with the heater (03.17). In this case, the exit gas is warmed to ambient temperature with the defrost water heater (15.50).

F. ECONOMICS AND LAUNCH TREND DATA

The cost estimates found in this report have been derived by the same methods that Air Products and Chemicals, Inc. would use to establish the costs for a firm price quotation to a customer. Quotations have been received from vendors on the major items of equipment not ordinarily fabricated by Air Products and Chemicals, Inc. The allowance for engineering time was made assuming that there would be close communication between the purification equipment fabricator and engineering, e.g., APCI designers and engineers and APCI fabricators, and that the pipelines and storage would be subcontracted to others, with engineering performed by the prime contractor.

The total investment is based on starting construction on or before December 31, 1965. Escalation in costs can be expected at a rate of increase of approximately five percent per year. A closer approximation can be obtained by applying individual increases to each of the main categories, e.g., construction, pipelines, etc.

This estimate is based on a turnkey system* capable of collecting, transporting,

*A turnkey system is defined as delivery by the contractor to the purchaser of a system that has passed its performance tests and is ready for operation by the purchaser's trained personnel.

storing, and purifying the helium used at the VAB and at the pads of Launch Complex 39 and at the pads of Launch Complexes 34 and 37. There are four distinct systems identified by the following:

1. VAB only.
2. VAB and the pads of LC-39.
3. VAB and the pads of LC-39 with 6 Saturn IB's launched per year from LC-34 and LC-37.
4. VAB and the pads of LC-39 with 12 Saturn IB's launched per year from LC-34 and LC-37.

Each system would consist of a collection network composed of takeoffs from the hydrogen vent lines to the burn ponds at each pad or from the helium vent line at the VAB. This takeoff would consist of a set of automatic valves regulated by an analyzer which would determine the contents of the vent line. After the valves had opened into the recovery system, the blowers would be started by a pressure indicator controller in the transfer lines, and the gas would then be transported to the storage containers. The storage containers are hemispheres approximately 150 feet in diameter. Each container holds slightly more than 1 million standard cubic feet (10,000 lb.) of contaminated helium. Each storage unit is actually composed of two parts: a hypalon-coated nylon inner hempisphere complete with a bottom, the contaminated helium container; and a hypalon-coated, neoprene-impregnated, nylon outer container which holds its hemispherical shape by air pressure supplied from a continuously operating blower. The outer container serves as the protective shell for the helium container inside. These containers are designed to withstand 75 mph winds and to be collapsed and covered with nylon mesh nets during winds of higher velocities. Containers could be designed for winds to 125 mph, but could not be designed to withstand the objects usually carried by such winds. Each container can be deflated and lashed down within a half-hour period. The blowers are equipped with automatic emergency power generators in case of power failure. The volume of storage required for various launch rates can be found in Figure 29.

The contaminated helium is taken from storage and processed by the purification plant for introduction into the Grade A helium system. The plant is sized to meet the demands of several launch and checkout patterns. These plant sizes are shown in Figure 28.

Operating costs have been separated into two main categories - fixed annual operating costs and variable operating costs, or utilities used per launch. The fixed annual operating costs are labor, maintenance, chemicals and lubricants, and NASA's G&A on these items. G&A was assumed to be 10% of operating costs. The variable operating costs are the various utilities such as power, water, oxygen, liquid nitrogen, and NASA's G&A on these items. Operating costs may be found in Figure 31 and in Table XIII.

The investment includes all purification equipment, storage, pipelines, compressors, and a building to house that equipment located at the CCF. The building is assumed to be a prefabricated steel structure which is available commercially in standard sizes. The helium interfaces have been established as the vent lines near the burn ponds, the vents of the VAB, and the inlet manifolding of the CCF compressors. With the exception of liquid nitrogen, for which local storage has been provided, the utility interfaces are the equipment battery limits, or within 30 feet of the particular items requiring the utilities, whichever is closer. The investment includes all equipment necessary for a turnkey facility. Investment totals can be found in Table XII.

The unit cost of recovery for helium can be found in Figure 32 and is shown to range between \$2.15/lb. and \$.58/lb. for all cases which include the launch pads, and between \$3.08/lb. and \$.72/lb. for cases involving the VAB only.

Expected annual savings can be found in Figure 33; expected 10-year savings in Figure 34. The expected 10-year savings has a wide range. Minimum is \$1,420,000, and maximum is \$42,560,000.

With regard to investment, one item is of interest. Assuming that pads A and B at LC-39 are to be used for launching and that construction of pad C is for standby use, then, if pad C is not outfitted for helium recovery and is never actually used, but kept on standby status, the total investment for recovery of the helium from 18 launches per year would be:

1. \$2,811,310 for LC-39 only.
2. \$3,486,125 for LC-39 with 6 SIB launches per year.
3. \$3,488,465 for LC-39 with 12 SIB launches per year.

The new unit recovery cost would then be:

1. (\$281,131 + \$133,950 + \$77,683)/938,100 lb. = 53¢/lb.
2. (\$348,613 + \$134,101 + \$81,641)/1,011,600 lb. = 56¢/lb.
3. (\$348,847 + \$134,146 + \$81,335)/1,085,100 lb. = 52¢/lb.

The new savings per year would be:

1. \$4,221,450 - \$492,764 = \$3,728,686 or \$37,290,000 for 10 years.
2. \$4,552,200 - \$564,355 = \$3,987,845 or \$39,880,000 for 10 years.

3. $4,882,950 - $564,328 = $4,318,622 or $43,190,000 for 10 years.

These savings are effected by the reduced investment in compressors and pipelines by not outfitting pad C.

As can be seen in Figure 35 and in Table XIV, the payout for any of the four helium recovery systems is extremely attractive. For four launches per year at the VAB only, the least desirable case, the payout period is less than 3-1/2 years. The shortest payout period is three-fourths of a year and is the result of 18 launches per year with recovery equipment at LC-39. The payout period calculation used was:

$$\text{Payout Period (years)} = \frac{\text{Investment (\$)}}{\left(\begin{array}{c}\text{Value of Helium} \\ \text{Recovered (\$/yr.)}\end{array} - \begin{array}{c}\text{Operating} \\ \text{Costs (\$/yr.)}\end{array}\right) + \begin{array}{c}\text{Depreciation} \\ \text{Allowance (\$/yr.)}\end{array}}$$

G. EQUIPMENT DESCRIPTION

1. Helium Compressors and Blowers.

a. Pad and VAB Area.

The helium blowers located at the VAB and the pad areas handle the flow of contaminated helium from the vehicle vent line to the low-pressure storage container located at each compressor-converter facility. These blowers are positive displacement units and are sized to handle the maximum peak and to overcome the transmission line pressure drop. Because of the intermittent duty requirement, this type of unit is preferable.

The helium blower located at the low-pressure storage container of Complexes 34 and 37 transfers the contaminated helium from this container to the low-pressure storage at the purification area of Complex 39. Because of the small flow and a more continuous duty, a reciprocating, nonlubricated compressor is used.

b. Purification Areas.

(1) Main Compressor - Item 01.20. This compressor is a multi-stage reciprocating nonlubricated unit which boosts the contaminated helium feed from the low-pressure storage container to 155 psia. This unit will be water-cooled, and includes intercoolers, aftercoolers, gages, safety valves, and manual bypass unloading valves piped to the suction. Packing will be of the double seal type. Bleed from the suction relief valves, vents, and blowdown pipe is to the compressor suction.

(2) Adsorber Reactivation Compressor - Item 01.22. This compressor will be a single-stage unit used to circulate

reactivation gas in the nitrogen adsorber reactivation system at 120 psia. It can be a nonlubricated reciprocating compressor, a leaktight, diaphragm compressor, or a rotary unit. The unit shall be water-cooled with intercoolers, aftercoolers, and gages.

2. Warm Purification Equipment.

a. Deoxo Converter Equipment - Items 02.10, 03.13, 05.80. Three sets of deoxo conversion equipment are required. Each set consists of one stainless steel vessel, containing a catalyst on an inert base, a water cooler, and a water separator. The hydrogen contained in the contaminated helium is reacted with oxygen over the catalyst in the vessel (item 02.10) to form water. Since the heat of reaction increases the temperature to approximately 900°F, the contaminated helium stream is then cooled in a standard tube-and-shell exchanger (05.70) to 100°F. The condensed water is then removed in a carbon steel separator (03.13). This separator is a tangential entry, centrifugal type.

b. Helium Drier System - Item 03.10. The drier (03.10) will consist of two cylindrical carbon steel pressure vessels, arranged for alternating service on an 8-hour, manually operated, reactivation cycle. A filter will be provided to protect downstream equipment against desiccant dust. The driers are designed to dry the contaminated helium to a dewpoint of -120°F.

c. Drier Reactivation Equipment - Items 01.21, 02.91, 03.11, 03.12, 03.17. The drier reactivation system consists of a blower (01.21), water separator (03.12), filter (02.91), electric heater (03.17), and water cooler (03.11).

A rotary reactivation gas blower is provided and will be driven by a 440-volt, 3-phase, 60-cycle electric motor. A filter is provided on the suction side to protect the blower against desiccant dust.

The reactivation heater is a thermostatically controlled, 440-volt, 3-phase, 60-cycle electric element contained inside a carbon steel casing.

The water cooler is a standard tube-in-shell exchanger that uses water.

3. Helium Purification Group.

a. Main Exchanger - Item 05.21. The main exchanger is a three-fluid, coiled-tube heat exchanger. It is used to cool the contaminated helium and to warm the product and nitrogen streams. The tube passes are copper, wrapped on a steel core and enclosed in a stainless steel shell.

b. Cold Exchanger - Item 05.22. The cold exchanger is a three-fluid, coiled-tube heat exchanger and is used to cool the contaminated helium and to warm the product and nitrogen streams. The tube passes are copper, wrapped on a steel core and enclosed in a stainless steel shell.

c. Phase Separator - Item 07.81. The entrained liquid nitrogen is removed in a stainless steel, tangential entry, centrifugal separator.

d. Nitrogen Adsorber Group - Items 01.22, 02.92, 08.23, 08.25, 08.27, 08.41, 08.43. This system consists of two parallel vessels for final cleanup of the product helium stream. The adsorption takes place on a bed of activated carbon, which is contained in the stainless steel vessels. The carbon is reactivated with helium, which is compressed by the adsorber reactivation compressor (01.22) and heated in a thermostatically controlled electric heater (08.43). During recycling for heatup the reactivation gas is cooled in a standard shell-and-tube exchanger that uses water. It is then returned to the compressor suction. A filter (02.92) protects the compressor from desiccant dust. During the cooldown period, the compressed reactivation gas is cooled to operating temperature in two coiled-tube exchangers, the adsorber cooldown exchanger (08.25) and the adsorber cooldown economizer exchanger (08.27). The adsorber cooldown exchanger is a two-fluid, coiled-tube heat exchanger wound on a steel core and enclosed in a stainless steel shell. The adsorber cooldown economizer heat exchanger is a three-fluid unit. The tube passes are copper, wrapped on a steel core and enclosed in a stainless steel outer shell.

4. Nitrogen Refrigeration Equipment.

a. Liquid Nitrogen Storage - Item 16.10. The liquid nitrogen storage unit is a dual vessel, vacuum-insulated cryogenic liquid storage tank complete with all controls and piping necessary for normal automatic operation and liquid withdrawal. The inner vessel is constructed of a suitable cryogenic material such as stainless steel of 9% nickel alloy steel. The outer shell is carbon steel. Liquid withdrawal is accomplished by pressurization from an integral ambient air vaporizer. The annular space between the inner and outer vessels shall be filled with perlite, sanocel or another approved vacuum filler material.

b. Vacuum Pump - Item 01.30. The vacuum pump is a standard reciprocating unit complete with aftercooler, gages, and controls.

This unit maintains a vacuum of 2 psia on the shell of main and cold exchangers, thereby subcooling the nitrogen in the shell to -340°F.

5. Instrumentation.

Adequate instrumentation controls and accessory devices are provided to assure proper operation of the purification unit with a minimum of operating personnel. All controls must be selected for fail-safe operation. Contaminated helium compressors within the pad area must be remotely operated. The control panel shall be located on or near the purification plant.

6. Electrical Wiring and Equipment.

All electrical equipment shall be 440 volts, 3-phase, 60-cycle. Starters, electrical control panels, and circuit protection shall be included.

Instruments shall be 110 volts, single-phase, 60-cycle.

7. Valves, Piping, and Controls.

Process piping, fittings, valves, and controls within the helium purification cold box shall be suitable for cryogenic temperatures.

All lines, valves, and equipment of the contaminated helium and product circuit must be completely welded and thoroughly leak tested. The valves shall have either a positive bellows seal or have double packing with a bleed to the feed gas stream.

Line sizes of the contaminated helium transmission lines are as shown in Drawings SK-4-1165-55.60-1E, SK-4-1165-55.60-2E and SK-4-1165-55.60-3E.

8. Helium Purification Plant Cold Box.

All vessels and equipment operating at cold temperatures will be supported on a structural steel framework and enclosed within a jacket of welded and bolted carbon steel panels. Rockwool insulating material will fill the void spaces within the jacket. A portion of the nitrogen vapor from the storage tank will be bled into this jacket to maintain a positive pressure.

All equipment which is subjected to temperatures below -320°F will be further enclosed within a stainless steel inner jacket. A positive pressure above the outer jacket pressure will be maintained in the inner jacket by bleeding a portion of the Grade A helium product into it. The cold box shall be suitable for outdoor installation.

A typical cold box arrangement is shown in Drawing SK-4-1165-11.1-1D. This arrangement is for Case 110, which has outer jacket dimensions of 10'6" W x 11'0" D x 17'3" H and weighs approximately 60,000 pounds.

9. <u>Facility Layout</u>.

The location of the helium purification plant is presently contemplated to be at the compressor-converter facility of launch Complex 39, MILA. As shown in Drawing SK-4-1165-57-1D, titled Preliminary Compressor Building Layout, Helium Purification Equipment, an approximate area of 4500 sq. ft. is required.

H. MATERIAL SELECTION AND FABRICATION STANDARDS

1. All process vessels will be designed, fabricated, tested and stamped in accordance with the provisions of the 1962 ASME Code for Unfired Pressure Vessels, including all the latest addenda, where applicable. ASTM Specifications will govern the materials of construction used for pressure vessels.

2. All heat exchangers which use sea water as a coolant shall use aluminum brass tubes and naval brass tube sheets. All remaining parts of the heat exchanger in contact with sea water shall be of nonferrous construction or be suitably protected.

   All heat exchangers outside of the cold box shall be in accordance with TEMA Class "C" mechanical standards.

3. All pressure piping shall be designed in accordance with the following codes and standards, where applicable, including general and supporting sections of the codes or standards which deal with requirements for internal pressure, flexibility, materials, fabrication, and testing.

   a. All piping inside of the helium purification cold box shall be in accordance with ASA B31.5-1962, <u>Refrigeration Piping Systems</u>.

   b. All piping outside of the helium purification cold box shall be in accordance with ASA B31.1-1955, <u>Code for Pressure Piping, Section 2, Industrial Gas and Air Piping Systems</u>.

   c. ASME Unfired Pressure Vessel Codes, Section VIII, 1962, Design, Fabrication, and Inspection Requirements shall be used to supplement the Piping Code A.S.A. BB1-1, when the Piping Code does not provide for conditions such as potential brittle fracture which are known to be present.

   d. The B16 group of A.S.A. standards shall apply to pipefitting details.

PART VIII

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The total quantity of helium gas required for the checkout and launch of one Saturn V - Apollo space vehicle is 69,491 pounds of Grade A quality helium. Of this quantity, it is feasible to recover 52,125 pounds.

2. The total quantity of helium gas required for the checkout and launch of one Saturn IB space vehicle is 16,005 pounds of Grade A quality helium. Of this quantity, it is feasible to recover 12,500 pounds.

3. The most economical helium repurification cycle for Complex 39, MILA, is the catalytic oxidation and cryogenic separation and adsorption cycle.

4. Contaminated helium gas is most economically stored at essentially atmospheric pressure in flexible coated-nylon containers.

5. The most economical helium recovery and repurification system for Launch Complex 39 consists of a helium purification plant (catalytic oxidation and cryogenic separation and adsorption cycle) located at the compressor-converter facility, low-pressure storage located at the compressor-converter facility, and low-pressure piping to the storage from the VAB and from each of the pads.

6. The most economical helium recovery system for Launch Complexes 34 and 37 consists of low-pressure storage at the compressor-converter facility of Complexes 34 and 37 and a low-pressure piping and blower network to transmit the contaminated helium gas from this storage to the low-pressure storage located at the compressor-converter facility of Complex 39. The contaminated helium gas is repurified at the plant located at Launch Complex 39.

7. Helium collection and repurification at the VAB only is economically feasible for launch rates of four or more Saturn V vehicles per year.

8. Helium collection and repurification at the VAB and at the pads of Complex 39 is economically feasible for launch rates of four or more Saturn V vehicles per year.

9. Helium collection and repurification at the VAB and at the pads of Complex 39 and at the pads of Complexes 34 and 37 is economically

feasible for launch rates of four or more Saturn V vehicles per year plus six or more Saturn IB vehicles per year.

10. Helium collection and repurification at Complexes 34 and 37 is economically attractive only as part of the recovery system for Complex 39.

11. The total anticipated saving for a 10-year Saturn program ranges from 1.4 million dollars for 4 Saturn V vehicles per year (VAB operation only) to 42.6 million dollars for 18 Saturn V vehicles per year plus 12 Saturn IB vehicles per year (VAB plus pad operation of LC-39 and pad operation of LC-34 and LC-37).

12. The payout period for the helium recovery system investment ranges from a maximum of 3.5 years for VAB operation only at a launch rate of 4 Saturn V vehicles per year to a minimum of 0.8 years for 18 Saturn V vehicles per year.

13. The helium recovery system consisting of the commercially available equipment described herein, can be designed, procured, and erected for operation within a time period of approximately 18 months under normal economic conditions.

14. Safety is a definite consideration when handling hydrogen and hydrogen mixtures. However, pertinent data based on experience is available from many sources. Acceptable standards have been established, and the design and installation of safe hydrogen systems is now common practice. By using commercially available oxygen and hydrogen analyzer-controllers and system vents, and by employing the safety standards established for hydrogen service, combustible hydrogen mixtures within the helium recovery system can positively be avoided. Since the average oxygen composition within the system is in the parts-per-million range, and since the background gas is 90% helium or greater, the maximum allowable concentration of hydrogen that can be tolerated in the system (storage and/or process lines), without the chance of forming a combustible mixture with air entering through a major leak is 8%. Of course any mixture of helium and hydrogen by itself is harmless. (The maximum allowable concentration of hydrogen in a mixture with air without the formation of a combustible mixture is 4.5%.* However, this percentage can be increased to 8% on a helium mixture of 90% helium or higher because of the high thermal conductivity of helium which tends to dissipate the heat of combustion, thereby dampening the combustion reaction.)

15. The vehicle checkout and launch schedules and the quantities of helium

*Bureau of Mines Bulletin, No. 503, page 21.

used, as presented herein, are considered to be minimum. Should the scheduled checkout and launch periods be lengthened, the quantity of helium used for blanketing per vehicle would increase slightly as would plant operating cost. However, it is felt that more helium will actually be used during the major purge operations, and that the economics and payout period presented in this report would therefore not be adversely affected.

B. RECOMMENDATIONS

This report recommends that:

1. A helium recovery and repurification system be installed at Launch Complex 39 for Complexes 34, 37 and 39 to recover and repurify the helium used for checkout and launch of the Saturn V and Saturn IB launch vehicles.

2. All contaminated helium gas be stored, prior to repurification, at essentially atmospheric pressure in flexible coated-nylon containers.

3. All contaminated helium gas be transported in pipelines of low-pressure design (approximately 15 psi).

4. The contaminated helium be purified by a plant using a catalytic oxidation and cryogenic separation and adsorption cycle.

5. The helium recovered from LC-39, LC-34, and LC-37 be purified and introduced into the Grade A system at LC-39 for reuse, with makeup helium gas for LC-34 and LC-37 supplied by purchase from the Bureau of Mines.

6. The helium purification system be operated from the control room at the purification plant. The contaminated helium pickup switch valves shall be activated by gas analyzers, which will automatically direct the helium into the system.

7. The pipeline compressors be regulated by pressure indicator controllers.

8. The final design and procurement of equipment for a helium recovery system be started immediately to permit operation of the helium recovery system during the forthcoming Saturn IB program. This permits partial payoff of the recovery system investment prior to the start of the Saturn V launch schedule, and also provides a familiarization and training period for operating personnel.

APPENDIX A

SAMPLE CALCULATIONS

GENERAL ASSUMPTIONS

In the Vertical Assembly Building it is assumed that no limitation, other than economic, exists to the provision of piping for recovering helium from the vehicle.

On the Mobile Launch Structure no additional piping is allowed. For preliminary considerations, however, it is assumed that where necessary the RP-1 and LOX fill-drain transmission lines can be tapped. The economic feasibility of this will be determined later in this study.

1. Sample calculation for:

   Blanket pressurization.

   Vehicle checks.

   Propellant utilization calibration purge.

   Purge prior to transport.

   Calculations will be for the S-II LH_2 fuel tank, although they are typical for the other tanks. Since these operations all are performed at the VAB and since they will occur sequentially and/or concurrently, the calculated impurity level is averaged over all four operations. Specific assumptions for these operations are:

   a. Tank is initially filled with nitrogen at 0 psig pressure.

   b. A blanket pressure of 5 psig is applied every night and relieved every morning.

   c. The vent line is left open for 7 hours during each work day to maintain atmospheric pressure in the tank. This results in diffusion of air into the tank through the vent line.

   d. Only half of the helium involved in the 20 vehicle checks is recoverable. The other half is lost to the atmosphere in the process of performing the vehicle tests.

   e. The vehicle is transported to the pad with 5 psig pressure of pure helium.

   Blanket Pressurization.

   Volume of S-II LH_2 fuel tank = 38,400 $ft.^3$ For 5 psig pressure every night, requires

$$V = (38{,}400)\left(\frac{5}{15}\right) = 12{,}800 \text{ SCF}$$

or $$W_{He} = (12{,}800)\left(\frac{4}{386}\right) = 133 \text{ lb.}$$

For 45 days this is

$$V_{He} = (45)\ (12{,}800) = 575{,}000 \text{ SCF}$$

$$W_{He} = (45)\ (133) = 5{,}960 \text{ lb.}$$

Add volume of N_2 initially in the tank.

$$V_{Total} = 575{,}000 + 38{,}400 = 613{,}400 \text{ SCF}$$

Vehicle Checks.

Twenty pressurizations to one-half flight ullage pressure (15 psig), or

$$W_{He} = (38{,}400)\left(\frac{1}{2}\right)\left(\frac{15}{15}\right)(20)\left(\frac{4}{386}\right) = 3{,}980 \text{ lb.}$$

Only 1/2 is recoverable, or

$$W_{He} = \frac{3980}{2} = 2{,}000 \text{ lb.}$$

$$V = \left(\frac{386}{4}\right)(2{,}000) = 193{,}000 \text{ SCF}$$

Pressurization Utilization Calibration Purge.

For a time period of 1 hour, using purge rate of item 2.17, Drawing 13M50097,

$$W_{He} = (62.7)\ (60) = 3{,}760 \text{ lb.}$$

$$V = (3{,}760)\left(\frac{386}{4}\right) = 363{,}000 \text{ SCF}$$

Purge Prior to Transport.

By item 2.17 of Drawing 13M50097,

$$W_{He} = 3{,}260 \text{ lb.}$$

$$V_{He} = (3{,}260)\left(\frac{386}{4}\right) = 314{,}000 \text{ SCF}$$

Since transported to pad with 5 psig tankful, subtract

$$V = (38{,}400)\left(\frac{20}{15}\right) = 51{,}000 \text{ SCF}$$

Recoverable helium is

$$V_{He} = 314{,}000 - 51{,}000 = 263{,}000 \text{ SCF}$$

$$W_{He} = 263{,}000 \left(\frac{4}{386}\right) = 2{,}730 \text{ lb.}$$

Impurities.

Initial tankful of N_2.

$$V = 38{,}400 \text{ ft.}^3$$

Diffusion into open vent.

This can be estimated from the general time dependent diffusion equation

$$\frac{\delta \eta_{air}}{\delta \theta} = D_{air-He} \frac{\delta^2 \eta_{air}}{\delta z^2}$$

Where η_{air} = moles of air

θ = time

D_{air-He} = mass diffusivity coefficient

z = length

The solution to this partial differential equation is the error integral which is plotted in McAdams, Heat Transmission, third edition, page 39. Using this solution, the concentration of air in helium in the vent line at the end of seven hours can be plotted. The mass diffusivity coefficient, D_{air-He}, can be estimated from equation (8-12) of Reid & Sherwood, Properties of Gases and Liquids.

$$D_{air-He} = \frac{.001858\, T^{3/2} \left[\frac{(M_{He})+(M_{air})}{(M_{He})\ (M_{air})}\right]^{1/2}}{\Sigma^2_{He-air}\, \Omega_D}$$

The values of $\Sigma_{He\text{-}air}$ and Ω_D are given in the reference. Calculation gives

$$D_{air\text{-}He} = .69 \frac{Cm^2}{Sec}$$

For a vent of constant cross section, the concentration of air in helium averages 30% in a 20 ft. length (0% beyond 20 ft.) at the end of 7 hours. Applying this result to the S-II LH_2 fuel tank (2 - 7" vent lines) gives a volume of

$$V_{air} = (.3) \frac{\Pi \ (7/12)^2}{4} (2) \ (20) \ (45) = 145 \text{ ft.}^3$$

or

$$V_{N_2} = 115 \text{ ft.}^3$$

$$V_{O_2} = 30 \text{ ft.}^3$$

Adding the 115 $ft.^3$ nitrogen to the initial tankful of 38,400 $ft.^3$ shows it to be negligible.

The total volume of recoverable contaminated helium is

$$\begin{array}{r} 613{,}400 \\ 193{,}000 \\ 363{,}000 \\ \underline{263{,}000} \\ 1{,}432{,}400 \end{array} \text{ ft.}^3 \text{ (approximately 14,324 lb.)}$$

Average nitrogen impurity

$$\% \ N_2 = \frac{38{,}515}{1{,}432{,}400} = 2.7\%$$

Average oxygen impurity

$$\% \ O_2 = \frac{30}{1{,}432{,}400} = 20 \text{ ppm}$$

2. Sample calculation for purge after LOX load test on S-II LH_2 fuel tank. Assume tank initially filled with hydrogen at -50°F.

$$V_{H_2} = \frac{530}{410} (38{,}400) = 49{,}600 \text{ SCF}$$

By item 2.47 of Drawing 13M50097

$$W_{He} = 2,425 \text{ lb.}$$

$$V_{He} = 2,425 \frac{(386)}{(4)} = 234,000 \text{ ft.}^3$$

$$V_{Total} = 283,600$$

$$\% H_2 = \frac{49,600}{283,600} = 17.5\% H_2$$

3. Sample calculation for LH_2 load test on S-II LH_2 fuel tank. There are three operations involving helium -

   a. Ullage pressurization

   b. Pressure-drain of LH_2

   c. Inerting of LH_2 tank

   From Drawing 13M50097

   a. Item 2.3

   $$W_{He} = 210 \text{ lb.}$$

   b. Item 2.30

   $$W_{He} = 2,000 \text{ lb.}$$

   c. Item 2.47

   $$W_{He} = 2,425 \text{ lb.}$$

   Total weight of helium = 4,635 lb.

   $$V_{He} = (4,635) \frac{(386)}{(4)} = 447,000 \text{ SCF}$$

   Impurities.

   If the assumption is made that the collection of impure helium begins at the time the liquid interface passes the point which defines the closed system to be purged, the amount of hydrogen included in the helium will be determined by boiloff and diffusion and by pockets of nondrainable liquid in the tank. Using methods similar to those in No. 1 above, the amount of hydrogen due to boiloff and diffusion is

$$W_{H_2} = 75 \text{ lb.}$$

Nondrainable liquid remains in the triangular space above the common LH_2 - LOX bulkhead and below the LH_2 fill-drain line. The dimensions are approximately 2 ft. by 10 inches right triangle on a 33 foot diameter, or

$$V = \frac{(2)\left(\frac{10}{12}\right)}{2} (33) = 86.8 \text{ ft.}^3$$

$$W_{H_2} = (87)\ (4.42) = 383 \text{ lb. } H_2$$

There are also five suction lines to the engines of 6-inch diameter and approximately 2 ft. in length which account for another 9 lbs. Thus, total H_2

$$\begin{array}{r} 75 \\ 383 \\ \underline{9} \\ 467 \end{array} \text{ lb. } H_2$$

$$V_{H_2} = 467 \left(\frac{386}{2}\right) = 90{,}000 \text{ SCF}$$

$$V_{Total} = 537{,}000 \text{ SCF}$$

$$\%\ H_2 = \frac{90{,}000}{537{,}000} = 16.7\%$$

4. Calculations for pressurized helium bottles. For all helium bottles, the amount of gas used is obtained from the applicable items listed in Drawings 13M50096, 13M50097, and 13M50098. For miscellaneous tests at the VAB, it is assumed that the gas is pure and that only one-half of the total used is recoverable, the remainder being lost to the atmosphere during the various tests.

5. Calculation for inerting of LH_2 cross-country fill-drain line. For 10" I.D. pipe, 1,800 ft. long:

$$V = \frac{\Pi}{(4)} \frac{(10)^2}{(144)} (1{,}800) = 980 \text{ ft.}^3$$

No reference is available to determine amount used to inert. If assumed to require less than 1% H_2, use approximately 100 volumes of helium or

$$V_{He} = (100)\ (980) = 98{,}000 \text{ ft.}^3$$

$$W_{He} = 98{,}000\ \frac{4}{380} = 1{,}000 \text{ lb.}$$

At pad 37B, this purge takes 1/2 hour. If the purge rate for the S-II LH_2 tank (26.4 lb./min.) is used, (item 2.47 of Drawing 13M50097)

$$V_{He} = (26.4)\ (30) = 800 \text{ lb.}$$

Since there is reasonable agreement between these two values, use the higher value, 1,000 lb. For the four purges which are recoverable, the line contains two volumes of hydrogen vapor at saturation conditions,

$$P = .08 \text{ lb/ft.}^3$$

$$V_{H_2} = (2)\ (.08)\ (980)\ \left(\frac{386}{2}\right) = 30{,}200 \text{ ft.}^3$$

$$V_{He} = (4)\ (98{,}000) = 392{,}000 \text{ ft.}^3$$

$$V_{Total} = 422{,}200 \text{ ft.}^3$$

$$\%_{H_2} = \frac{30{,}200}{422{,}200} = 7.2\%$$

APPENDIX B

Air Products and Chemicals, Inc. August 11, 1964

Trip Report of D. Kelemen, D. McGinnis, and P. Fennema
Helium Recovery Study of MILA
NASA Contract Number NAS10-1472
APCI Project No. 00-4-1165

The following summarizes the helium usage information obtained from various personnel within NASA who are directly associated with the Saturn V and Apollo Program.

This report covers the period from August 2 through 4 at Huntsville, Alabama and August 5 through August 9 at Cape Kennedy, Florida.

It should be noted that several discrepancies exist between the information obtained from the various sources. No attempt has been made to resolve these discrepancies at this time, but merely to report the data obtained.

ERRATA SHEET

TRIP REPORT

HELIUM RECOVERY STUDY FOR MILA

The below listed corrections and/or additions have been prepared for incorporation as shown into the Trip Report, dated August 11, 1964, "Helium Recovery Study for MILA".

1. Revise LN_2 price in item 1a, page B-4 to $39.50/ton.

2. Change item 3, page B-6 to read psia.

3. Add the following after first sentence of item 5, page B-6 (probably 3 to 4 times per test).

4. Revise second sentence of item 6, page B-6 to "of one shift per day normal . . . . . ".

5. Delete second sentence of item 9, page B-6 in its entirety and substitute the following sentence. "The first two purges are to inert the fuel system before and after the hydrogen load test and a third purge is to inert the fuel system after precooling the fuel tank prior to loading of LOX.

6. Substitute the word "head" for "heel" in second line of item 12, page B-6.

7. Substitute the word "spheres" for "cylinders" in first line of item 13, page B-6.

8. Delete the words "is not permissible" in item 2, page B-7 and substitute "can be avoided (by-pass)".

9. Substitute the word "helium" for "nitrogen" in item 4, page B-7.

10. Revise second sentence of item 5, page B-7 to read: "is presently "0" leakage with soap bubble test for 5 minutes per joint".

11. Change temperature of item 2a, page B-7 to read minus 320°F.

12. Change temperature of item 2e, (2), page B-7 to read 250°F.

13. Revise person contacted to read: Messrs. E. Fannin, W. Backus, J. Humphrey.

14. Add the following after the word "bottles" in item 1a, page B-9 "in LOX tank".

15. Revise second line of item 1c, page B-9 to read: ....temperatures once with RP-1 aboard and once without RP-1 aboard.

16. Substitute the word "vehicle" for "engines" in item 2a, page B-9.

17. Change second line of item 4a, page B-10 to read: ....three times to pad safety at 1000 psi.

18. Add the following at the end of the third sentence of item 4a, page B-10. (This operation may require that the bottle pressurization be performed more than once.)

19. Modify the first line of item 5, page B-10 to read as follows: The LH_2 supply line is purged before and after use . . . . . is obtained.

20. Delete table listed under item 4, page B-4 in its entirety and substitute the following:

TANK CAPACITY - WATER VOLUME $FT.^3$

STAGE	RP-1	LOX	LH2
S-IC	29,474	47,495	
S-II		12,910	38,400
S-IVB		2,828	10,457

The S-IC RP-1 and LOX tank material is aluminum 2219-T87. The S-II LH_2 and LOX tank material is aluminum 2014-T6. The S-IVB LH2 and LOX tank material is aluminum 2014-T6 although the S-IVB tank is insulated on the inside. The type of insulating material as furnished by Douglas is unknown to the Future Studies Branch at this time.

Monday - August 3, 1964

Persons Contacted: A. R. Raffaelli, NASA
G. Bottomley, Chrysler (assigned to NASA)

General introduction and orientation.

Persons Contacted: Messrs. M. D. Beck and G. Eudy (GSE from MSFC)
Messrs. Beck and Eudy discussed their group's function and requested that they be contacted during Phase II and III of this study for the purpose of determining the compatibility of proposed recovery schemes with existing hardware.

The afternoon was spent in general discussions with Messrs. Raffaelli and Bottomley as summarized below:

1. The following delivered prices to Cape Kennedy of cryogenic propellants and liquids were stated:

    a. LN_2 - \$57/ton

    b. LOX - \$38/ton

    c. LH_2 - \$1460/ton (\$0.73/lb.)

2. The following factors to be used for this study were received:

    a. Power - 1.225¢/KWH

    b. Operation Labor - APCI to use same rates presently experienced at Patrick AFB LOX Plant.

    c. Labor Efficiency - To be determined by APCI

3. Actual helium used based on purchasing records for Saturn launches of SA-5 and SA-6 were given as

    a. SA-5 33,340 lbs. of helium

    b. SA-6 22,163 lbs. of helium

    NOTE: S-IV was operational on both vehicles

4. The following tank capacities were received:

Stage	LH_2 Tank	LOX Tank
S-II	38,400 Cu. Ft.	12,910
S-IVB	10,457	2,828

5. The following ground rules applicable to this study were discussed:

   a. At present, it is contemplated to deliver helium to Cape Kennedy in high-pressure railroad cars and not as a liquid.

   b. Equipment within the complex is required to withstand the overpressure experienced during normal launch.

   c. Only normal launch will be considered in this study although some consideration should be given to expendability of equipment in case of a catastrophe.

   d. Economics shall be based on:

      (1) Ten (10) year amortization period

      (2) Five (5) year payout period

6. The KSC Operation Plan (preliminary), consisting of several manuals, was reviewed. The following information concerning helium usage was extracted:

   a. Page 6.10.3.3 - One Saturn V checkout and launch is predicted to require 7,784,000 SCF (77,840 lb.) of helium.

   b. Page 6.10.3.4 - One Apollo checkout and launch is predicted to require 200 SCF (2 lb.) @ 6000 psig.

Tuesday - August 4, 1964

Person Contacted: Mr. B. H. Adams

The following information was received from Mr. Adams and associates:

1. All tanks of all stages arrive at Cape Kennedy with 3 - 5 psig nitrogen except the S-IV tank for which helium is specified.

2. Continuous helium purge of hydrogen tanks are performed using the pressurizing line as inlet and the drain line as outlet. The following data applies:

Stage	Rate	Time	Supply
S-II	62#/min	52 min	600 psig
S-IVB	20#/min	50 min	600 psig

NOTE: Venting of helium purge is expected to be accomplished through vents exiting external to the VAB.

3. Pressure test LH2 fuel tanks at following pressure:

Stage	Rate
S-II	20 - 25 psig
S-IVB	20 - 25 psig

NOTE: Full working pressure of these tanks is 40 psig.

4. One pressure test of helium spheres is performed in VAB at 1500 psig. The pressure in the spheres may not exceed 1500 psig in VAB for safety reasons.

5. The subsystem checkouts require pressurization of control spheres for approximately 12 tests at VAB. Doubt was expressed at the recovery possibility from the control spheres during these tests.

6. Allowance should be made for the additional helium usage because of one shift per week normal operation which would require that all tests be completed within an eight hour day or restarted.

7. All LH_2 fuel tanks are pressurized to 3 - 5 psig with helium prior to departure of Mobile Launch Structure with vehicle aboard from the VAB to the pad.

8. A full pressure test is performed at pad on all control spheres at design temperatures.

9. A propellant load test and two purging operations will be performed at the pad. The first purge is for inerting the fuel system after the hydrogen load test and the second purge is to inert the fuel system after precooling the fuel tank prior to loading of LOX.

   NOTE: During the load test, the fuel and oxidizer tanks will not be filled simultaneously.

10. The pressurization of the control spheres is required for two additional subsystem tests at the pad.

11. The fuel tank insulation is on the inside of the S-IVB stage and on the outside of the S-II stage. The material of the S-II fuel tank is an aluminum alloy.

12. Because of the position of the LH_2 fuel tank drain line, a two foot heel of LH_2 remains in the tank after draining.

13. Helium cylinders are presently used in the S-IVB stage to drain the LOX tanks after a cryogenic load test.

Person Contacted: Mr. N. Porter

The following information was received from Mr. Porter:

1. The helium supply lines on Mobile Launch Structure were discussed. The present design has two 3" double extra strong lines supplying helium to Mobile Launch Structure with only one line, 2.3" ID, approximately 300 ft. long, 6000 psi service, ascending the tower.

2. A capability exists to vent the helium lines at bottom of the Mobile Launch Structure. Backflow through the helium filters is not permissible.

3. The proposed procedure is to blow down the 6000-psi helium line to atmospheric pressure prior to transporting the Mobile Launch Structure back to VAB or parking area.

4. A positive pressure is then maintained in helium lines using nitrogen.

5. The estimated helium loss associated with the Mobile Launch Structure helium lines is 0.5 cc/min per fitting.

Persons Contacted: Messrs. T. White and R. Barclay

The following information was received from Messrs. White and Barclay:

1. The blowdown loss expected in each CCF helium compressor is approximately 500 SCF (5 lb.)/compressor/day. Five (5) compressors are planned for Complex 39. The contaminants are oil, air, and water.

2. Helium is to be used in regeneration of cold trap purification system. Since the design of this unit is incomplete, the following information was provided:

   a. Initial conditions:

      minus 350°F, 6000 psi

   b. Total contaminants to be based on 10-hour operation at 750 SCFM (7.5 lb.) helium containing 500 ppm impurities (80% N_2 and 20% O_2).

   c. Total volume of system

      15 CF water volume

   d. Bed volume

      3 CF water volume

   e. Proposed reactivation procedure

      (1) Depressurize bottle to 1 atm gage

      (2) Heat to 350°F in closed system bleeding excess pressure

(3) Purge and cool with pure helium till helium purity is 50 ppm

(4) Repressurize bottle to 6000 psi for standby

3. Compressors for Complex 39 are Joy Compressor having 110-125 psig suction, 6000 psig discharge (capability to 10,000 psi discharge), and 150 SCFM.

4. The replenishment rate at Complex 37 is 2 hours/day, 7 days/week. Present practice is to pump helium trailers down to 200 psig minimum thereby eliminating contamination of the tube trailers.

Wednesday - August 5, 1964

Persons Contacted: Messrs. J. B. Stone, W. Paulus, J. Jason

The following estimated quantities of helium required for each launch of the following vehicles were obtained:

Saturn I.

S-I	Booster	200,000 SCF (2000 lb.)
S-IV	2nd Stage	1,970,000 SCF (19,700 lb.)

Saturn IB.

S-IB	Booster	400,000 SCF (4000 lb.)
S-IVB	2nd Stage	3,940,000 SCF (39,400 lb.)

Saturn V.

S-IC	Booster	2,000,000 SCF (20,000 lb.)
S-II	2nd Stage	15,760,000 SCF (157,600 lb.)
S-IVB	3rd Stage	3,940,000 SCF (39,400 lb.)

The quantities of helium required for Saturn IB and Saturn V were estimated using the following:

Saturn IB = 2 x Saturn I
Saturn V = 10 x Saturn I

The accuracy of these estimates is not known. These quantities are assumed to be order of magnitude quantities of helium for these future programs. In addition, the initial checkout of the VAB will require 18.5 million SCF (185,000 lb.) and 4 million SCF (40,000 lb.) for each launch pad.

Persons Contacted: Messrs. E. Fannin, J. Backus, R. Humphrey

The following information was obtained from this group which is associated with mechanical aspects of launch vehicle:

1. A fifty-eight day check-out and assembly schedule is assumed. During this time the LOX and LH_2 tanks of the S-II and S-IVB stages are kept under a 3 to 5 psig blanket pressure with helium. This pressure is relieved approximately 45 out of the 58 days to accommodate various tests requiring the tanks to be at atmospheric pressure. The blanket pressure of 3 to 5 psig is always applied overnight even if an operation is not completed. During this time, it is possible that an additional purge will be required following the opening of one or more tanks for inspection and/or repair. This opening of the tank is not a normal operation but has occurred in the past.

Specific information applicable to each stage is as follows:

1. S-IC Booster

   a. The helium bottles are pressurized to 1000 to 1500 psig at ambient temperature approximately 40 times for various tests at the VAB.

   b. The bottles are pressurized 3 or 4 times to 1000, 1500 psig and at ambient temperature at the pad and once to 3000 psig at cryogenic temperatures.

   c. The fuel tank is pressure tested to flight ullage pressure at ambient temperatures twice with no RP-1 aboard.

   d. The LOX tank is cycled once at the pad to flight ullage pressure with no LOX aboard, followed by pressure test to the same pressure with LOX aboard.

2. S-II 2nd Stage

   a. The LOX and LH_2 tanks are pressurized to 1/2 flight ullage pressure approximately 20 times for engine checks in VAB.

   b. The helium bottles are pressurized approximately 40 times to 1500 psig for various tests at VAB.

   c. There is a one hour purge of the LOX and LH_2 tanks to achieve -65°F dew point for the calibration of the propellant utilization (P.U.) probe. This purge is accomplished by opening fill-drain valve and purging through pressurization valve.

   d. There is a purge with grade A helium prior to moving vehicle to pad, prior to propellant load tests, and prior to loading for flight.

   e. Purging of the external insulation on LH_2 tank is required prior to propellant load test and prior to flight.

3. S-IVB 3rd Stage

All operations are the same as those for the S-II stage with the exception of the purge of the LH_2 tank insulation which is not required on this S-IVB stage.

4. Engines

a. S-II stage has 5 engine control spheres which are purged for 5 minutes and pressurized three times to 5 psig. Venting is accomplished through the engines. These bottles are also pressurized once to approximately 600 psig for a leak check. Operating pressure is 1250 psig.

b. S-IVB stage has one engine control sphere on which the same operations are performed as for the S-II stage engine control spheres.

5. The LH_2 supply line is purged after use until a purity of better than 99% helium is obtained. This purge normally takes one half hour on pad 37B.

Thursday - August 6, 1964

Persons Contacted: Messrs. T. White, M. Hellingsworth, W. Bain

The compressor-converter facility which services Complex 34 and Complex 37 was visited. Helium is delivered to the facility in tube trailers of 40,000 SCF (400 lb.) capacity each. Helium is expanded from the initial trailer pressure of approximately 2400 psig to the compressor suction pressure of 120 psig with the pressure in the trailer tubes maintained above 200 psig minimum. The 3 Cardair compressors of 140 SCFM capacity each charge the helium to the high-pressure storage areas at each complex at a pressure of 6000 psig. Helium is lost during the initial purge of the trailer-to-compressor connecting lines, and during compressor blowdown at the end of each charging operation.

Persons Contacted: Messrs. W. R. Meyer, R. Engel, R. C. Butterworth

For the LEM fuel pressurization system, approximately 55 lbs. of helium is needed. This quantity is used three times in the industrial area for checkout operations and is loaded once on the pad for flight. The flight operating pressure is 4000 psig.

For the service and command modules 90 pounds of helium is used for the purging of the propellant tanks. These tanks also are helium pressure tested at approximately 300 psig or 1-1/2 times the 200 psig operating pressure. The fuel tank has a capacity of 2000 gallons and the oxidizer tank has a capacity of 2500 gallons. Approximately 200 pounds of helium is used in the propulsion systems checkout of the service module. This test is performed twice.

Negligible amounts of grade AA helium are used for purging the fuel cell.

Person Contacted: Mr. C. F. Brinkman

Confirmation of information received from W. R. Myers, R. Engel and R. C. Butterworth from an Industrial Area facilities standpoint. The industrial area has several 10,000 psig storage tubes only now holding helium at 6000 psig. Helium will only be used in the following five buildings of the Industrial Area:

1. Spacecraft Operation and Checkout Facility

2. Environmental Control Systems Building

3. Support Building

4. Hypergolic Test Building

5. Cryogenic Test Building

The only significant uses of helium in the industrial area are those quantities used for checkout of the Service Module and the Lunar Excursion Module.

Unrecoverable and negligible amounts will be used for welding and instrumentation checkout in the industrial area.

Person Contacted: Mr. L. S. Harris

Present plans are to equip completely only two highbays of the VAB with helium and other high-pressure gases and services. A 2" gaseous nitrogen line is the only existing vent planned; helium is to be vented directly in the building. (Design ventilation of VAB calls for one air change/hour.)

APCI was promised detail drawings of VAB plans, VAB area, and a piping flowsheet by the Future Studies Group of KSC, Huntsville.

Friday - August 7, 1964 - AM

Person Contacted: Mr. R. Burns

After initial introduction, there was a visual orientation of Complex 39, specifically the Mobile Launch Structure assembly and erection area, crawler-transport, assembly area, VAB, Launch Control Center, Compressor-Converter Facility, crawlerway, and Pad A.

Friday - August 7, 1964 - PM

The final stop was at Complex 37B for a visual orientation of an existing operational launch facility. A study was made of the type of attachments and connections commonly used for vehicle loading and of the type of ports which might be available for vent gas pick up.

TABLE I
REVISION NO. 1 - DATED NOVEMBER 17, 1964

SUMMARY OF HELIUM USAGE
SATURN V - APOLLO VEHICLE

Item No.	Operation	Location	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
	S-IC									
1.	PRESSURE CHECK RP-1 FUEL TANK	PAD	14	AMB	300	150	29,500	50% N_2	Recover from RP-1 fill-drain line.	
2.	ULLAGE PRESSURE RP-1 FUEL TANK	PAD	14	AMB	35	0	56,300	94% N_2	Negligible amount of helium. Propellant load test.	
3.	ULLAGE PRESSURE RP-1 FUEL TANK	PAD			35	0			For flight.	
4.	BLANKET PRESSURE LOX TANK	VAB	5	AMB	0	0	0	-	Gaseous nitrogen will be used on all LOX tanks.	1
5.	PRESSURE CHECK LOX TANK	PAD	22	AMB	7,210	7,210	611,800	7.8% N_2	Recover from LOX fill-drain line.	1
6.	ULLAGE PRESSURE LOX TANK	PAD	22	-297	104	0	155,000	94% N_2	Negligible amount of helium propellant load test.	
7.	ULLAGE PRESSURE LOX TANK	PAD			104	0			For flight.	

TABLE I (Continued)

Item No.	Operation	Location	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. (Ft.^{3})	Impurities	Remarks	Rev.
8.	HELIUM BOTTLES MISC. TESTS	VAB	1,500	AMB	4,810	2,400	232,000	Pure		
9.	HELIUM BOTTLES MISC. TESTS	PAD	1,500	AMB	480	91	23,000	62% N_2		
10.	HELIUM BOTTLES	PAD	3,000	-295	646	440	62,000	32% N_2	Recover from RP-1 fill drain line, propellant load test.	
11.	HELIUM BOTTLES	PAD			646	0			For flight.	
11.1	TOTALS S-IC STAGE	VAB PAD FLIGHT			4,810 8,775 785 14,370	2,400 7,891 0 10,291	232,000 726,300 0 958,300			1
	S-II									
12.	BLANKET PRESSURE LH_2 FUEL TANK	VAB	5	AMB	5,960	5,960	613,400			
13.	VEHICLE CHECKS LH_2 FUEL TANK	VAB	8	AMB	3,980	2,000	193,000			
14.	P.U. PURGE LH_2 FUEL TANK	VAB	5	AMB	3,760	3,760	363,000	2.7% N_2 20 ppm O_2	Impurities average for the four operations shown.	
15.	PURGE LH_2 TANK PRIOR TO TRANSPORT	VAB	5	AMB	3,260	2,730	263,000			

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
16.	PRESSURE TEST LH_2 FUEL TANK	PAD	10	AMB	270	270	25,600	Pure		
17.	PURGE OF LH_2 FUEL TANK	PAD	-	-	0	0	0	-		1
18.	INERT LH_2 TANK AFTER LOX LOAD TEST	PAD	-	-	0	0	0	-	Inerting operation not required since loading of LOX and LH_2 performed on same day.	1
18.1	P.U. CALIBRATION PRIOR TO LAUNCH	PAD	5	AMB	3,760	3,760	363,000	Pure		
19.	ULLAGE PRESSURE LH_2 FUEL TANK	PAD	15	-423	210	210				
20.	DRAIN LH_2 FUEL TANK	PAD	15	-423	2,000	2,000	537,000	16.7% H_2	LH_2 Load Test.	
21.	INERT LH_2 TANK AFTER LH_2 LOAD TEST	PAD	5	-423	2,425	2,425				
22.	ULLAGE PRESSURE LH_2 FUEL TANK	PAD			210	0			For flight.	
23.	BLANKET PRESSURE LOX TANK	VAB	5	AMB	0	0	0		Gaseous nitrogen will be used on all LOX tanks.	1

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
24.	VEHICLE CHECKS LOX TANK	VAB	11	AMB	1,960	980	94,500	5.0 N_2 155 ppm O_2	Impurities average for the four operations shown.	
25.	P.U. PURGE LOX TANK	VAB	5	AMB	1,585	1,585	153,000			
26.	PURGE LOX TANK PRIOR TO TRANSPORT	VAB	5	AMB	0	0	0		Operation not required.	1
26.1	FULL PRESSURE TEST	PAD	22	AMB	1,817	1,817	188,480	9.2% N_2		1
26.2	P.U. PURGE LOX TANK	PAD	5	AMB	1,585	1,585	153,000	Pure		1
27.	ULLAGE PRESSURE LOX TANK	PAD	22	-297	81	81	61,520	88% N_2		1
28.	DRAIN LOX TANK	PAD	22	-297	0	0	0	-		1
29.	PURGE LOX TANK	PAD	5	-297	0	0	0			1
30.	ULLAGE PRESSURE LOX TANK	PAD			81	0			For flight.	
31.	HELIUM BOTTLES MISC. TESTS	VAB	1,500	AMB	711	350	34,000	Pure		
32.	HELIUM BOTTLES LOAD TESTS	PAD	3,000	-275	68	68	5,600	Pure	Recover at end of propellant load tests.	

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. (Ft.^{3})	Impurities	Remarks	Rev.
33.	HELIUM BOTTLES ON ENGINES	PAD	3,000	AMB	18	0			Discharged through engines.	
34.	HELIUM BOTTLES	PAD			86	0			For flight.	
35.	THRUST CHAMBER PURGE AND COOL-DOWN	PAD	0	-250	700	0			Discharged through engines. Load test.	
36.	THRUST CHAMBER PURGE AND COOL-DOWN	PAD			700	0			For flight.	
37.	MISC. PURGE AND BUBBLING	PAD			160	0			Individual quantities small. Load test.	
38.	MISC. PURGE AND BUBBLING	PAD			160	0			For flight.	
39.	TOTALS S-II STAGE	VAB PAD FLIGHT			21,216 13,094 1,237 35,547	17,365 12,216 0 29,581	1,713,900 1,334,200 0 3,048,100			
	S-IVB									
40.	BLANKET PRESSURE LH_2 FUEL TANK	VAB	5	AMB	1,630	1,630	167,500			

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. (Ft.^{3})	Impurities	Remarks	Rev.
41.	VEHICLE CHECKS LH_2 FUEL TANK	VAB	10	AMB	1,440	700	67,500			
42.	P.U. PURGE LH_2 FUEL TANK	VAB	5	AMB	1,200	1,200	116,000	2.4% N_2 25 ppm O_2	Impurities average for the four operations shown. Incl. Item 40.	
43.	PURGE LH_2 TANK PRIOR TO TRANSPORT	VAB	5	AMB	990	845	81,500			
44.	PRESSURE TEST LH_2 FUEL TANK	PAD	20	AMB	145	145	13,960	Pure		1
45.	PURGE OF LH_2 FUEL TANK	PAD	5	AMB	0	0	0		Inerting operation not required since LOX and LH_2 loading performed on same day.	1
46.	INERT LH_2 TANK AFTER LOX LOAD TEST	PAD	5	-50	0	0	0			
47.	ULLAGE PRESSURE LH_2 FUEL TANK	PAD	20	-423	16.5	16.5	Inc. in Item 49		LH_2 load test.	
48.	DRAIN LH_2 FUEL TANK	PAD	22	-423	418	418	Inc. in Item 49		LH_2 load test.	
49.	INERT LH_2 TANK AFTER LH_2 LOAD TEST	PAD	5	-423	990	990	195,000	30% H_2	LH_2 load test.	

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (°F)	Helium Used (lb.)	Helium Recoverable (lb.)	Total Vol. (Ft.^{3})	Impurities	Remarks	Rev.
49.1	P.U. PURGE OF LH_2 TANK	PAD	5	AMB	1,200	1,200	116,000	Pure		1
50.	ULLAGE PRESSURE LH_2 FUEL TANK	PAD			16.5	0			For flight.	
51.	BLANKET PRESSURE LOX TANK	VAB	5	AMB	0	0	0		Gaseous nitrogen used.	1
52.	VEHICLE CHECKS LOX TANK	VAB	15	AMB	565	280	27,000	8.3% N_2 0.2% O_2	Impurities average for the two operations shown.	1
53.	P.U. PURGE LOX TANK	VAB	5	AMB	43	43	4,150			1
54.	PURGE LOX TANK PRIOR TO TRANSPORT	VAB	5	AMB	0	0	0		Operation not required.	1
54.1	FULL PRESSURE TEST LOX TANK	PAD	29	AMB	386	386	38,220	0.84% N_2		1
55.	ULLAGE PRESSURE LOX TANK	PAD	29	-297	8.5	8.5	820	Pure		1
56.	DRAIN LOX TANK	PAD	22	-297	0	0	0		Operation not required.	1
57.	PURGE LOX TANK	PAD	5	-297	0	0	0		Operation not required.	1

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. (Ft.3)	Impurities	Remarks	Rev.
57.1	P.U. PURGE LOX TANK	PAD	5	AMB	43	43	4,150	Pure		1
58.	ULLAGE PRESSURE LOX TANK	PAD			8.5	0			For flight.	
59.	HELIUM BOTTLES MISC. TESTS	VAB	1,000	AMB	1,877	935	90,200	Pure		1
60.	HELIUM BOTTLES FOR FULL PRESSURE TEST	PAD	1,000	AMB	32	32	3,100	Pure	Recover at end of LH_2 load test.	1
61.	HELIUM BOTTLES FOR LOX TANK	PAD	3,100	-410	397	397	38,300	Pure	Recover at end of LH_2 load test.	
62.	HELIUM BOTTLES	PAD			495	0			For flight.	
63.	THRUST CHAMBER PURGE AND COOL-DOWN	PAD	0	-410	140	0			Discharged through engines. Load test.	
64.	THRUST CHAMBER PURGE AND COOL-DOWN	PAD			140	0			For flight.	
65.	MISC. PURGES	PAD			17	0			One half flight, one half propellant load test.	

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
65.1	TOTALS S-IVB STAGE	VAB PAD FLIGHT			7,745 3,785 668 12,198	5,633 3,636 0 9,269	553,850 409,550 0 963,400			
	APOLLO									
66.	SER. MOD. PURGE	IND. A.	5	AMB	90					
67.	SER. MOD. PRESSURE TEST	IND. A.	300	AMB	130	630	63,000	3.5% N_2 80 ppm O_2	Impurities are average for operations shown.	
68.	PROPELLANT SYSTEM CHECKOUT	IND. A.	2,200 5,000	AMB	400					
69.	LEM ASCENT-DESCENT BOTTLES	IND. A.	3,500	-250	165					
70.	LEM ASCENT-DESCENT BOTTLES	PAD			55	0			For flight.	
71.	TOTALS APOLLO SPACE CRAFT	IND. A FLIGHT			785 55 840	630 0 630	63,000 0 63,000			

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^{o}F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
	COMPRESSOR-CONVERTER FACILITY									
72.	COMPRESSOR BLOWDOWN	CCF	6,000	AMB	1,500	1,500	145,000	Oil and Water	Assumed once per day for 58 days.	
73.	REGENERATE PURIFICATION SYSTEM	CCF	6,000	AMB	1,170	1,170	116,000	2.3% N_2 0.6% O_2	Based on preliminary size information and application to Complex 34 and 37 CCF only.	1
74.	TOTALS-CCF	(PAD 39) only			1,500	1,500	145,000			
	MOBILE LAUNCH STRUCTURE									
75.	BLOWDOWN PRIOR TO TRANSPORT	PAD	6,000	AMB	36	36	3,500	Pure		
	PAD AREA									
76.	INERTING LH_2 CROSS-COUNTRY FILL-DRAIN LINE	PAD	5	AMB*	5,000	4,000	422,200	7.2% H_2	Once after LH_2 load test, once before and after LH_2 load for flight.	1

* Initial purge temperature can be as low as -410^{o}F.

TABLE I (Cont.)

Item No.	Operation	Location	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
77.		OVERALL SUMMARY								
		AREA		POUNDS		POUNDS	SCF*			
77.1		VAB		33,771		25,398	2,499,750			
77.2		PAD		30,690		27,779	2,895,750			
77.3		FLIGHT		2,745		0	0			
77.4		IND. A.		785		630	63,000			
77.5		CCF		1,500		1,500	145,000			
77.6		GRAND TOTAL		69,491		55,307	5,603,500			

* SCF is based on 70^oF and 14.7 psia.

TABLE II
JANUARY 5, 1965 - REVISED FEBRUARY 9, 1965

SUMMARY OF HELIUM USAGE
SATURN IB VEHICLE

Item No.	Operation	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
	S-IB								
1.	PRESSURE CHECK RP-1 FUEL TANK	17.6	AMB	885	825	85,600	6.7% N_2	Recover from RP-1 fill-drain line.	
2.	ULLAGE PRESSURE RP-1 FUEL TANK	17.6	AMB	1	.54	6,700	99% N_2	Negligible amount of helium. Propellant load test.	
3.	ULLAGE PRESSURE RP-1 FUEL TANK			1	0			For flight.	
4.	PRESSURE CHECK LOX TANK	52.5	AMB	2,140	2,047	208,000	4.3% N_2	Recover from LOX fill drain line.	
5.	ULLAGE PRESSURE LOX TANK	52.5	-297	5	3.5	20,500	98% N_2	Negligible amount of helium. Propellant load test.	

TABLE II (Continued)

Item No.	Operation	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. (Ft.^{3})	Impurities	Remarks	Rev.
6.	ULLAGE PRESSURE LOX TANK			5	0			For flight.	
7.	HELIUM BOTTLES MISC. TESTS	1500	AMB	714	357	34,400	Pure	Requires piping to overboard vent.	
8.	HELIUM BOTTLES LOAD TEST	3000	AMB	126	126	12,200	Pure	Requires piping to overboard vent.	1
9.	HELIUM BOTTLES PRESSURIZATION			126	0			For flight.	
10.	MISC.			22	0			LOX bubbling, etc.	
11.	S-IB TOTALS								
	GROUND			3,893	3,355	340,200			
	FLIGHT			132	0	0			
				4,025	3,355	340,200			
	S-IVB								
12.1	BLANKET PRESS. LH_2 FUEL TANK	5	AMB	1,120	1,120			Included in item 12.2.	
12.2	VEHICLE CHECKS LH_2 FUEL TANK	10	AMB	1,440	700	316,000	3.3% N_2 35 ppm O_2	Impurities average for the four operations shown.	1

TABLE II (Cont.)

Item No.	Operation	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
12.3	P.U. PURGE LH_2 FUEL TANK	5	AMB	1,200	1,200			Included in item 12.2.	
12.4	PRESSURE TEST LH_2 TANK	20	AMB	145	145			Included in Item 12.2.	1
13.1	ULLAGE PRESSURE LH_2 FUEL TANK	20	-423	16.5	16.5				
13.2	DRAIN LH_2 FUEL TANK	22	-423	418	418	195,000	30% H_2	Tanking test.	
13.3	INERT LH_2 TANK AFTER LH_2 LOAD TEST	5	-423	990	990				
14.	P.U. PURGE LH_2 FUEL TANK	5	AMB	1,200	1,200	116,000	Pure		
15.	ULLAGE PRESSURE LH_2 FUEL TANK			16.5	0			For flight.	
16.	VEHICLE CHECKS LOX TANK	15	AMB	565	280	31,150	8.3% N_2 .2% O_2		
17.	P.U. PURGE LOX TANK	5	AMB	43	43				
18.	PRESSURE TEST LOX TANK	29	AMB	386	386	38,220	.84% N_2		

TABLE II (Cont.)

Item No.	Operation	Press. (psig)	Temp. (°F)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. (Ft.^{3})	Impurities	Remarks	Rev.
19.	ULLAGE PRESSURE LOX TANK	29	-297	8.5	7	14,000	75% N_2 20% O_2	Negligible amount of helium. Propellant load test.	
20.	P.U. PURGE LOX TANK	5	AMB	520	500	50,000	5.7% N_2		
21.	ULLAGE PRESSURE LOX TANK			8.5	0			For flight.	
22.	HELIUM BOTTLES MISC. TESTS	1,000	AMB	1,880	940	90,200	Pure		
23.A	HELIUM BOTTLES PRESSURE TEST	1,000	AMB	32	32	41,400	Pure		1
23.B	HELIUM BOTTLES TANKING TEST	3,100	-410	397	397				1
24.	HELIUM BOTTLES			495	0			For flight.	
25.	THRUST CHAMBER PURGE AND COOL-DOWN			280	0			Tank test and flight.	
26.	MISC. PURGES			17	0			Flight.	

TABLE II (Cont.)

Item No.	Operation	Press. (psig)	Temp. (^oF)	Helium Used (Lb.)	Helium Recoverable (Lb.)	Total Vol. ($Ft.^3$)	Impurities	Remarks	Rev.
27.	S-IVB TOTALS								
	GROUND			10,361	8,367	877,970			1
	FLIGHT			817	0	0			1
				11,178	8,367	877,970			
28.	LH_2 FILL-DRAIN LINE PURGE	5	-410 AMB	800	800	86,000	6.5% H_2	Once before and after tanking test, once before and after load for flight.	
	OVERALL SUMMARY								
	GROUND			15,055	12,500	1,304,170			1
	FLIGHT			950	0	0			1
				16,005	12,500	1,304,170			

TABLE III

COMPARATIVE COST ESTIMATES FOR HELIUM

PURIFICATION PLANT CYCLES

INVESTMENT

(3 & 6 Launches/Yr.)

	Case I-A	Case II	Case III	Case IV	Case V
Plant Capacity (lbs. of contaminated helium per hour)	20	46	46	46	46
Equipment Costs:					
Compression Equipment	$ 34,241	$ 36,503	$ 44,401	$ 44,401	$ 36,503
Cryogenic Equipment	45,734	93,912	109,356	110,019	128,603
Contractor's Design Engineering Cost	113,516	109,668	117,364	117,845	118,326
Instrumentation	32,500	32,500	32,500	32,500	32,500
Assembly & Piping	49,608	45,500	49,400	49,400	49,400
Insulation & Painting	6,500	6,500	6,500	6,500	6,500
Spares, Tooling, Inspection & Rework	10,400	10,400	10,400	10,400	10,400
Preparation for Shipment & Freight	3,900	3,900	3,900	3,900	3,900
Performance Bond	1,950	1,950	1,950	1,950	1,950
Performance Test	13,000	13,000	13,000	13,000	13,000
Total Equipment Costs	$311,349	$ 353,833	$388,771	$389,915	$401,082

TABLE IV

COMPARATIVE COST ESTIMATES FOR HELIUM PURIFICATION PLANT CYCLES

Capital Charges
(3 to 6 Launches/Yr.)

	1) Case I-A 2) Case II	1) Case I-A 2) Case III	2) Case IV	2) Case V
Plant Investment 1)	$ 311,349	$ 311,349	-	-
Plant Investment 2)	$ 353,833	$ 388,771	$ 389,915	$ 401,082
Total	$ 665,182	$ 700,120	$ 389,915	$ 401.082
Plant Construction Costs	34,500	34,500	17,250	17,250
Total Investment	$ 669,682	$ 734,620	$ 407,165	$ 418,332
Capital Cost/Year for 10 years	$ 69,968	$ 73,462	$ 40,717	$ 41,833

TABLE V

COMPARATIVE COST ESTIMATES FOR HELIUM

PURIFICATION PLANT CYCLES

Operating Costs
(3 Launches/Year)

	Case I-A Case II	Case I-A Case III	Case IV	Case V
Labor* Fixed Plant (s) - Same crew to operate both plants where applicable	$ 70,080	$ 70,080	$ 70,080	$ 70,080
Power @ 1.225¢/KWH VAB 65% on stream	733	733	733	733
PAD 35% on stream	565	659	659	640
Water @ 10¢/1000 gal. VAB 65% on stream	182	182	182	182
PAD 35% on stream	123	160	160	160
LIN @ $39.50/ton VAB 65% on stream	7,611	7,611	7,611	7,611
PAD 35% on stream	-	4,093	4,093	4,093
Misch Metal (Change 2 times/year for 3 Launches)	10,816	-	-	-
LOX @ $38.25/ton PAD only	738	738	738	738
Chem. & Lubes $3/HP/Yr. VAB	35	35	35	35
PAD	60	64	64	60
Maintenance 1.5%/Yr. of Investment	9,993	10,476	5,770	5,986
Operating Costs Subtotal	$100,936	$ 94,831	$ 90,125	$ 90,318

* 1 Superintendent
1 Ass't. Superintendent
4 Operators
1 Maintenance Man
1 Clerk

TABLE VI

COMPARATIVE COST ESTIMATES FOR HELIUM

PURIFICATION PLANT CYCLES

Operating Costs
(6 Launches/Year)

	Case I-A Case II	Case I-A Case III	Case IV	Case V
Labor* Fixed Plant (s) - Same crew to operate both plants where applicable	$ 70,080	$ 70,080	$ 70,080	$ 70,080
Power @ 1.225¢/KWH VAB 65% on stream	1,465	1,465	1,465	1,465
PAD 35% on stream	1,129	1,317	1,317	1,279
Water @ 10¢/1000 gal. VAB 65% on stream	363	363	363	363
PAD 35% on stream	246	319	319	319
LIN @ $39.50/ton VAB 65% on stream	15,159	15,159	15,159	15,159
PAD 35% on stream	-	8,187	8,187	8,187
Misch Metal (Change 5 times/year for 6 Launches)	27,040	-	-	-
LOX @ $38.25/ton PAD only	1,475	1,475	1,475	1,475
Chem. & Lubes $3/HP/Yr. VAB	35	35	35	35
PAD	60	64	64	60
Maintenance 1.5%/Yr. of Investment	9,993	10,476	5,770	5,986
Operating Costs Subtotal	$127,045	$108,940	$104,234	$104,408

* 1 Superintendent
1 Ass't. Superintendent
4 Operators
1 Maintenance Man
1 Clerk

TABLE VII

COMPARATIVE COST ESTIMATES FOR HELIUM

PURIFICATION PLANT CYCLES

Total Yearly Costs

3 Launches/Year	Case I-A Case II	Case I-A Case III	Case IV	Case V
Capital Charges	$ 69,968	$ 73,462	$ 40,717	$ 41,833
Operating Costs	100,936	94,831	90,125	90,318
NASA G&A @ 10%	10,094	9,483	9,013	9,032
Total Yearly Costs	$ 180,998	$ 177,776	$ 139,855	$ 141,183
6 Launches/Year				
Capital Charges	$ 69,968	$ 73,462	$ 40,717	$ 41,833
Operating Costs	127,045	108,940	104,234	104,308
NASA G&A @10%	12,705	10,894	10,423	10,431
Total Yearly Costs	$ 209,718	$ 193,296	$ 155,374	$ 156,572

TABLE VIII

COMPARATIVE COST ESTIMATES

FOR

EVALUATION OF ATMOSPHERIC STORAGE CONTAINERS

(1,000,000 Standard Cubic Feet)

	GATC	Goodyear	Birdair	CB&I	Viron
Life Expectancy, Years	10	10	10	10	10
Comparative Cost Estimates:					
1. Storage Container	$586,500	$235,000	$230,000	$316,300	$230,000
2. Product Blower, 10 HP	10,400	10,400	10,400	10,400	10,400
3. Inflation Blower, 5 HP	-	4,600	4,600	-	4,600
4. Attachment Hardware	-	2,300	2,300	-	4,600
5. Site Preparation	6,500	12,900	10,200	6,500	17,500
6. Foundation (excluding piling)	7,800	11,000	9,600	7,800	16,000
7. Erection	-	2,300	2,300	—	-
Total Capital Investment	$611,200	$278,500	$269,400	$341,000	$283,100
Maintenance - 10 Years (blower maintenance @ 1.5% investment plus painting of containers).	52,600	19,560	19,560	52,600	-
Replacement Costs	-	-	-	-	230,000
Operating Costs - 10 Years (Power, 445 KW @ $1.225¢/KWH)	39,700	47,700	47,700	39,700	47,700
Total Costs - 10 Years	$703,500	$345,760	$336,660	$433,300	$560,800
Cost of Storage, $/SCF	$0.70	$0.35	$0.34	$0.43	$0.56

TABLE IX

COMPARATIVE COST ESTIMATES

FOR

EVALUATION OF STORAGE PRESSURE

(Life Expectancy of All Cases - 10 Years)

	Main Storage Pressure - PSIA				
	15	75	265	365	435
1. Low Pressure Container					
995,000 SCF	$316,300	-	-	-	-
440,000 SCF	-	$187,500	$187,500	$187,500	$187,500
2. High Pressure Container 555,000 SCF	-	165,800	159,600	204,100	210,700
3. Product Blower, 10 HP	10,400	10,400	10,400	10,400	10,400
4. Storage Compressor	-	41,000 (25 HP)	52,000 (35 HP)	54,000 (45 HP)	55,000 (50 HP)
5. Plant Compressor	28,800 (30 HP)	20,000 (20 HP)	-	-	-
6. Site Preparation					
A. Low Pressure Container	6,500	1,200	1,200	1,200	1,200
B. High Pressure Container	-	2,000	900	800	700
7. Foundation					
A. Low Pressure Container	7,800	3,300	3,300	3,300	3,300
B. High Pressure Container	-	3,500	2,300	2,000	1,900
Total Capital Investment	$369,800	$434,700	$417,200	$463,300	$470,700
Maintenance @ 15% of Equipment Investment - 10 years	52,600	63,300	62,600	69,500	70,600
Power @ 1.225¢/KWH - 10 Years	39,700	45,580	48,940	50,440	50,900
Total Cost - 10 Years	$462,100	$543,580	$528,740	$583,240	$592,200
Cost of Storage, $/SCF	$0.46	$0.55	$0.53	$0.60	$0.60

TABLE X

COMPARISON OF ALTERNATES

HELIUM RECOVERY SYSTEMS - SATURN V

Alternate Number	1	2	3	4	5	6	7
Figure Number	9	10	11	12	13	14	15
Storage VAB 1.0 MMSCF	$ 345,000	$ 345,000	$ 345,000	*	*	$ 345,000	$
Storage PAD 2.5 MMSCF	862,500	862,500	862,500			862,500	862,500
He Purification Unit IV	407,165	407,165					407,165
He Purification Unit IV - Mobile			438,996			438,996	
Piping 5000' VAB to CCF	28,750		17,250				40,250
Piping 14,000' PAD to CCF	169,100		64,400				196,000
Trailers 4 ea. Impure He (550 ft.^{3} H_2O Vol.)		284,680					
Trailers Pure He (550 ft.^{3} H_2O Vol.)							
Portable 0-6000 psi Compressor		84,700				84,700	
Portable 0-5 psi 500,000 SCFH Blower							
Blowers (VAB, PAD, Portable)							62,930
Piping 4,000 ft. to Pure He Storage				-	-	46,000	
Total	$1,812,515	$1,984,045	$1,728,146			$1,777,196	$1,568,845
Depreciation	181,252	198,405	172,815			177,720	156,885

TABLE X

(CONTINUED)

Alternate Number	1	2	3	4	5	6	7
Labor	$ 70,080	$ 92,845	$ 70,080			$ 77,855	$ 77,855
Chemicals & Lubricants $3/HP/Yr.	99	99	99			150	852
Maintenance Material (1½%/Yr.)	26,929	29,502	25,922			26,658	23,533
NASA G&A (10%)	9,711	12,244	9,610	-	-	10,466	10,224
Subtotal	$106,819	$134,690	$105,711	*	*	$115,129	$113,020
Power - 6 Launches	3,210	3,210	3,210			3,210	4,068
Water - 6 Launches	660	660	660			660	660
LIN - 6 Launches	22,968	22,968	22,968			22,968	22,968
O_2 - 6 Launches	1,452	1,452	1,452			1,452	1,452
Moving Expenses - 6 Launches			480			480	
Miscellaneous		1,200				1,200	
NASA G&A (10%) - 6 Launches	2,832	2,952	2,880	-	-	3,000	2,916
Subtotal	$ 31,122	$ 32,442	$ 31,650			$ 32,970	$ 32,064
Total	$319,193	$365,537	$310,176			$325,819	$301,413
Weight of He Recovered (6 Launches)	312,684	312,684	312,684			312,684	312,684
$/lb. of He Recovered	1.02	1.17	0.99			1.04	0.96

*Alternates 4 and 5 were proven undesirable. No costs have been developed.

TABLE XI

COMPARISON OF ALTERNATE SYSTEM

SATURN I-B

Alternate Number		A		B		C		D
Storage (700,000 scf)		241,500		241,500		241,500		345,000
He Purification Plant IV	$	407,165	$	76,750	$	76,750	$	85,000
Pipeline 34-CCF 4100'		40,077		40,077		40,077		40,077
Pipeline 37-CCF 4300'		42,033		42,033		42,033		42,033
Pipeline CCF-MILACCF 30,000'						120,000		
Blower @ 34		1,750		1,750		1,750		1,750
Blower @ 37		1,750		1,750		1,750		1,750
Blower @ CCF						2,000		
Trailers - 4 ea. (550 cu. ft. H_2O Vol.)				284,680				
Compressor 0-6000 psi				84,700				
TOTAL	$	734,275	$	773,240	$	525,860	$	515,610
Depreciation Charges	$	73,428	$	77,324	$	52,586	$	51,561
Labor	$	70,080	$	59,460	$	43,000	$	70,080
Chems & Lubes $3/HP/yr.		99		60		90		99
Maintenance 1.5% x Invest.		11,014		11,600		7,888		7,734
SUBTOTAL	$	81,193	$	71,120	$	50,978	$	77,913
NASA G & A @ 10%		8,119		7,112		5,098		7,791
FIXED TOTAL OPERATING COSTS	$	89,312	$	78,232	$	56,076	$	85,704
Power (6 Launches)	$	1,974	$	1,200	$	1,578	$	1,980
Water (6 Launches)		288		180		222		288
LIN (6 Launches)		12,246						12,246
O_2 (6 Launches)		1,620						1,566
Share of MILA Operating Costs				12,840		12,840		
SUBTOTAL	$	16,128	$	14,220	$	14,640	$	16,080
NASA G & A @ 10%		1,613		1,422		1,464		1,608
TOTAL VARIABLE OPERATING COSTS	$	17,741	$	15,642	$	16,104	$	17,688
Annual Total Costs	$	177,525	$	171,198	$	124,766	$	154,953
Weight of He Recovered, Lbs.		77,616		77,616		77,616		77,616
Cost of Recovery - $/#	$	2.29	$	2.21	$	1.61	$	2.00

TABLE XII

COST ESTIMATE FOR HELIUM RECOVERY SYSTEM

INVESTMENT

Vehicle Launch Rate S-V	Vehicle Launch Rate S-IB	Helium Recovery Locations	Helium Purification Plant *	Contaminated Helium Storage	Contaminated Helium Compressors	Contaminated Helium Pipelines	Total Investment	Annual Depreciation Charge
4	-		995,817	363,489	136,500	133,344	1,629,150	162,915
6	-	VAB	995,817	363,489	136,500	133,344	1,629,150	162,915
12	-	Only	999,847	363,489	136,500	133,344	1,633,180	163,318
18	-		1,022,467	363,489	136,500	133,344	1,655,800	165,580
4	-	LC-39	1,114,450	794,951	214,500	687,409	2,811,310	281,131
6	-	VAB	1,114,450	794,951	214,500	687,409	2,811,310	281,131
12	-	&	1,114,450	794,951	214,500	687,409	2,811,310	281,131
18	-	PADS	1,125,277	884,999	253,500	1,188,834	3,452,610	345,261
4	6	LC-39	1,114,450	1,148,441	278,200	926,409	3,467,500	346,750
6	6	VAB	1,114,450	1,148,441	278,200	926,409	3,467,500	346,750
12	6	& PADS &	1,133,075	1,148,441	278,200	926,409	3,486,125	348,613
18	6	34 & 37	1,133,078	1,238,488	317,200	1,427,834	4,116,600	411,660
4	12	LC-39	1,122,675	1,148,441	278,200	926,409	3,475,725	347,573
6	12	VAB &	1,122,675	1,148,441	278,200	926,409	3,475,725	347,573
12	12	PADS &	1,135,415	1,148,441	278,200	926,409	3,488,465	348,847
18	12	34 & 37	1,135,418	1,238,488	317,200	1,427,834	4,118,940	411,894

* Includes construction cost for PAD blowers and accessories.

TABLE XIII

UNIT COST OF RECOVERY OF HELIUM

Launch Rate S-V	Launch Rate S-IB	Annual Depreciation Charge	Annual Labor Cost	Annual* Maintenance & Materials	Annual* Utilities Cost	Total Recovery Cost	Weight Of Helium Recovered	Unit Cost Of Recovery $/Lb.
VAB Recovery Only								
4	-	$ 162,915	$111,895	$ 19,613	$ 11,741	$ 306,164	99,600#	3.08
6	-	162,915	111,895	19,613	17,587	312,010	149,300	2.09
12	-	163,318	111,895	19,691	17,509	312,413	298,700	1.05
18	-	165,580	111,895	20,127	23,542	321,144	448,000	.72
VAB Plus LC-39 Pads								
4	-	281,131	111,895	21,847	30,862	445,735	208,500	2.14
6	-	281,131	111,895	21,847	46,274	461,147	312,700	1.48
12	-	281,131	111,895	21,847	92,584	507,457	625,400	.81
18	-	345,261	111,895	22,055	77,683	556,894	938,100	.60
VAB Plus LC-34, LC-37, and LC-39 Pads								
4	6	346,750	111,895	21,847	49,845	530,337	282,000	1.88
6	6	346,750	111,895	21,847	56,201	536,693	386,200	1.39
12	6	348,613	111,895	22,206	80,185	562,899	698,400	.81
18	6	411,660	111,895	22,206	81,641	627,402	1,011,600	.62
VAB Plus LC-34, LC-37, and LC-39 Pads								
4	12	347,573	111,895	22,055	48,837	530,360	355,500	1.49
6	12	347,573	111,895	22,055	58,670	540,193	459,700	1.18
12	12	348,847	111,895	22,251	79,770	562,763	772,400	.73
18	12	411,894	111,895	22,251	81,335	627,375	1,085,100	.58

*Includes NASA General and Administrative Costs of ten percent of all operating costs.

TABLE XIV

PAYOUT PERIOD CALCULATIONS

Launch Rate S-V	Launch Rate S-IB	Total Investment	Value of Helium Recovered	Total Operating Costs	Annual Depreciation Charge	(3)-(4)+(5)	Payout* Period In Years
VAB Recovery Only							
4	0	1,629,150	448,200	143,249	162,915	467,866	3.48
6	0	1,629,150	671,850	149,095	162,915	685,670	2.38
12	0	1,633,180	1,344,150	149,095	163,318	1,358,373	1.20
18	0	1,655,800	2,016,000	155,564	165,580	2,026,016	.99
VAB Plus LC-39 Pads							
4	0	2,811,310	938,250	164,604	281,131	1,054,777	2.67
6	0	2,811,310	1,407,150	180,016	281,131	1,508,265	1.86
12	0	2,811,310	2,814,300	226,326	281,131	2,869,105	.98
18	0	3,452,610	4,221,450	211,633	345,261	4,355,078	.79
VAB Plus LC-34, LC-37, and LC-39 Pads							
4	6	3,467,500	1,269,000	183,587	346,750	1,432,163	2.42
6	6	3,467,500	1,737,900	189,943	346,750	1,894,707	1.83
12	6	3,486,125	3,145,050	214,286	348,613	3,279,377	1.06
18	6	4,116,600	4,552,200	215,742	411,660	4,748,118	.87
VAB Plus LC-34, LC-37, and LC-39 Pads							
4	12	3,475,725	1,599,750	182,787	347,573	1,764,536	1.97
6	12	3,475,725	2,068,650	192,620	347,573	2,223,603	1.56
12	12	3,488,365	3,475,800	213,916	348,847	3,610,731	.97
18	12	4,118,940	4,882,950	215,481	411,894	5,079,363	.81

$$\text{*Payout Period (Yrs.)} = \frac{\text{Investment (\$)}}{\left[\underset{(3)}{\text{Value of Helium Recovered (\$/Yr.)}} - \underset{(4)}{\text{Operating Costs (\$/Yr.)}}\right] + \underset{(5)}{\text{Depreciation Charges (\$/Yr.)}}}$$

FIGURE I

SATURN I-B

WEIGHT OF RECOVERABLE HELIUM PER WORKING DAY

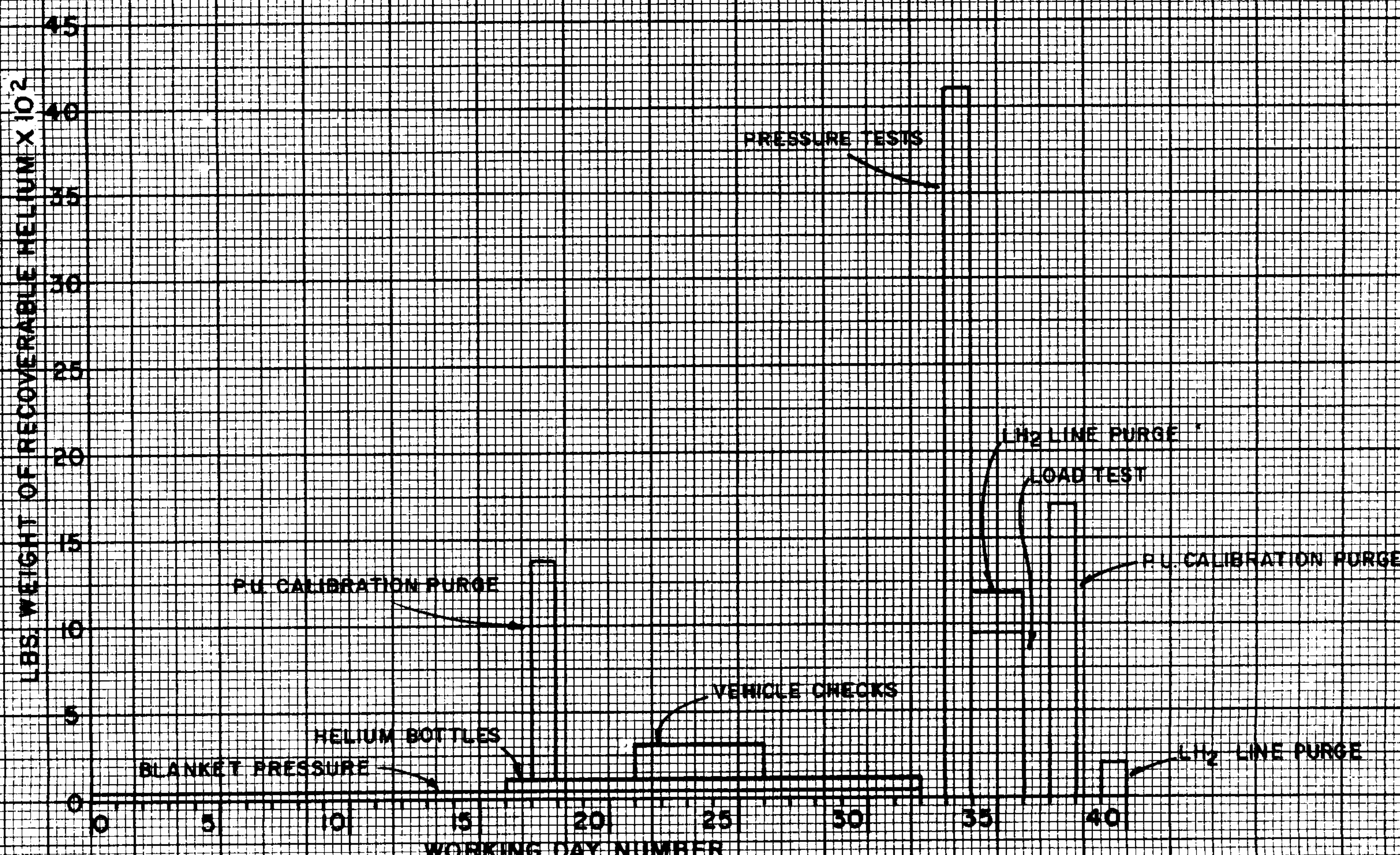


FIGURE IA
SATURN I-B
VOLUME OF RECOVERABLE CONTAMINATED HELIUM PER WORKING DAY

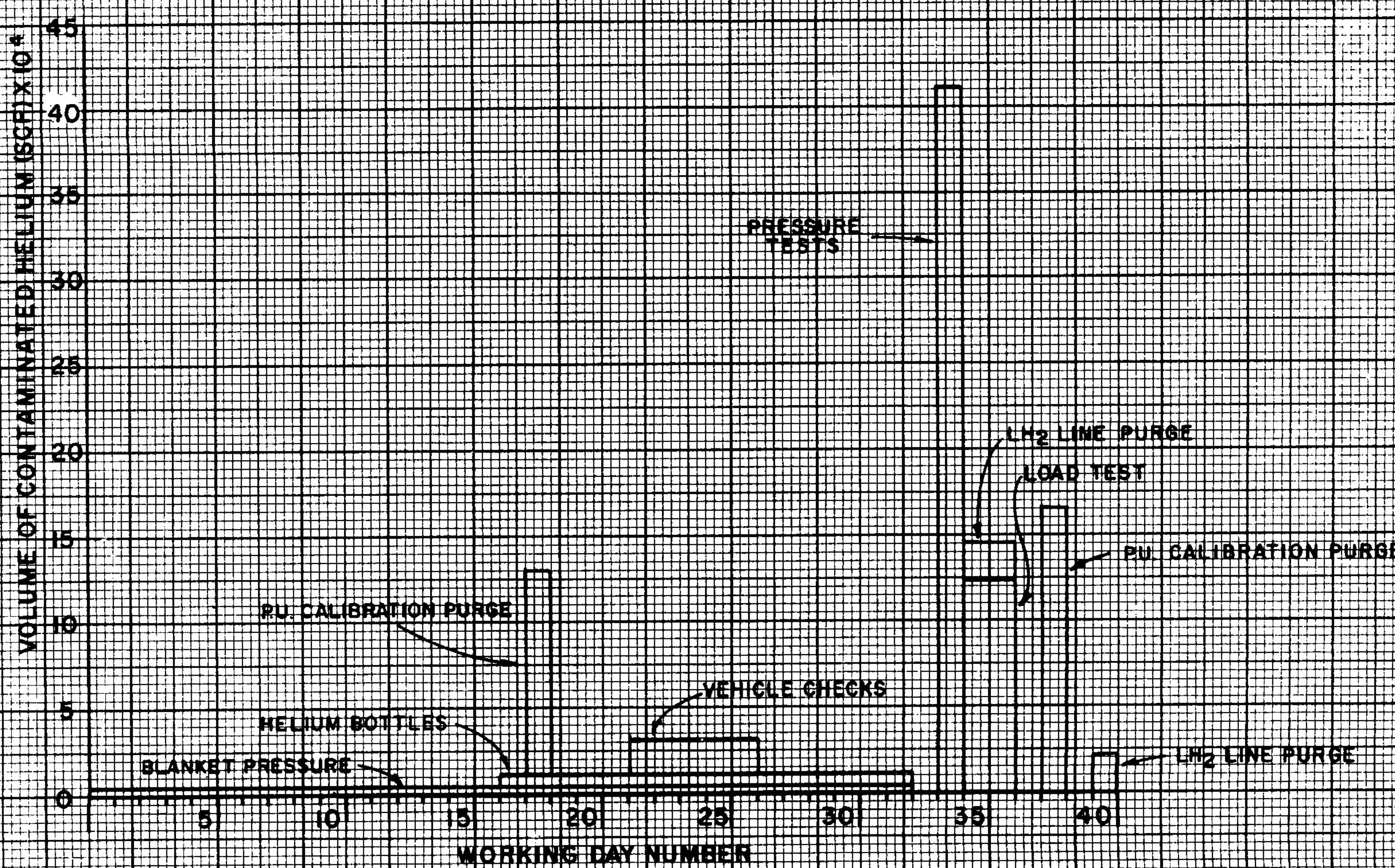
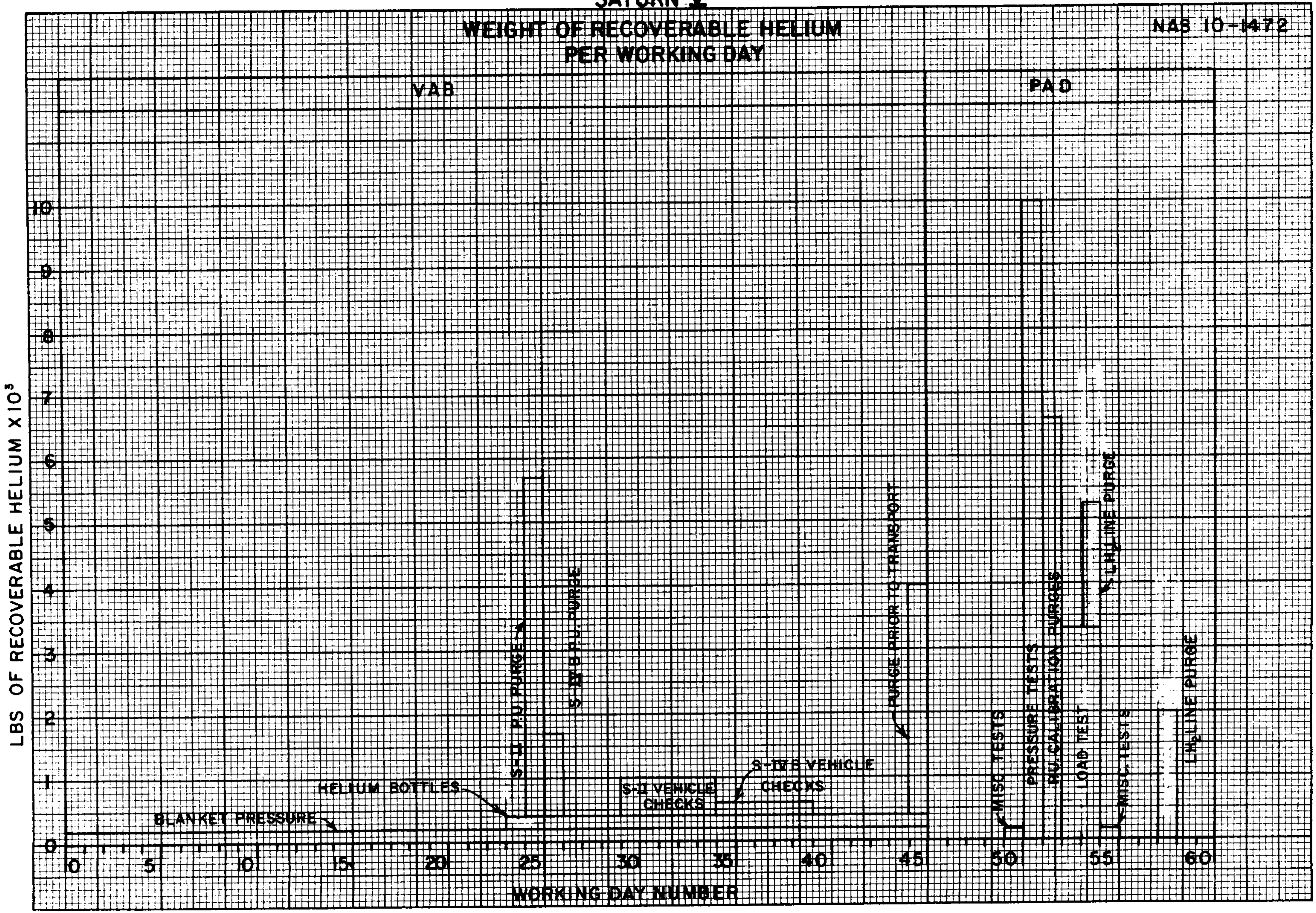


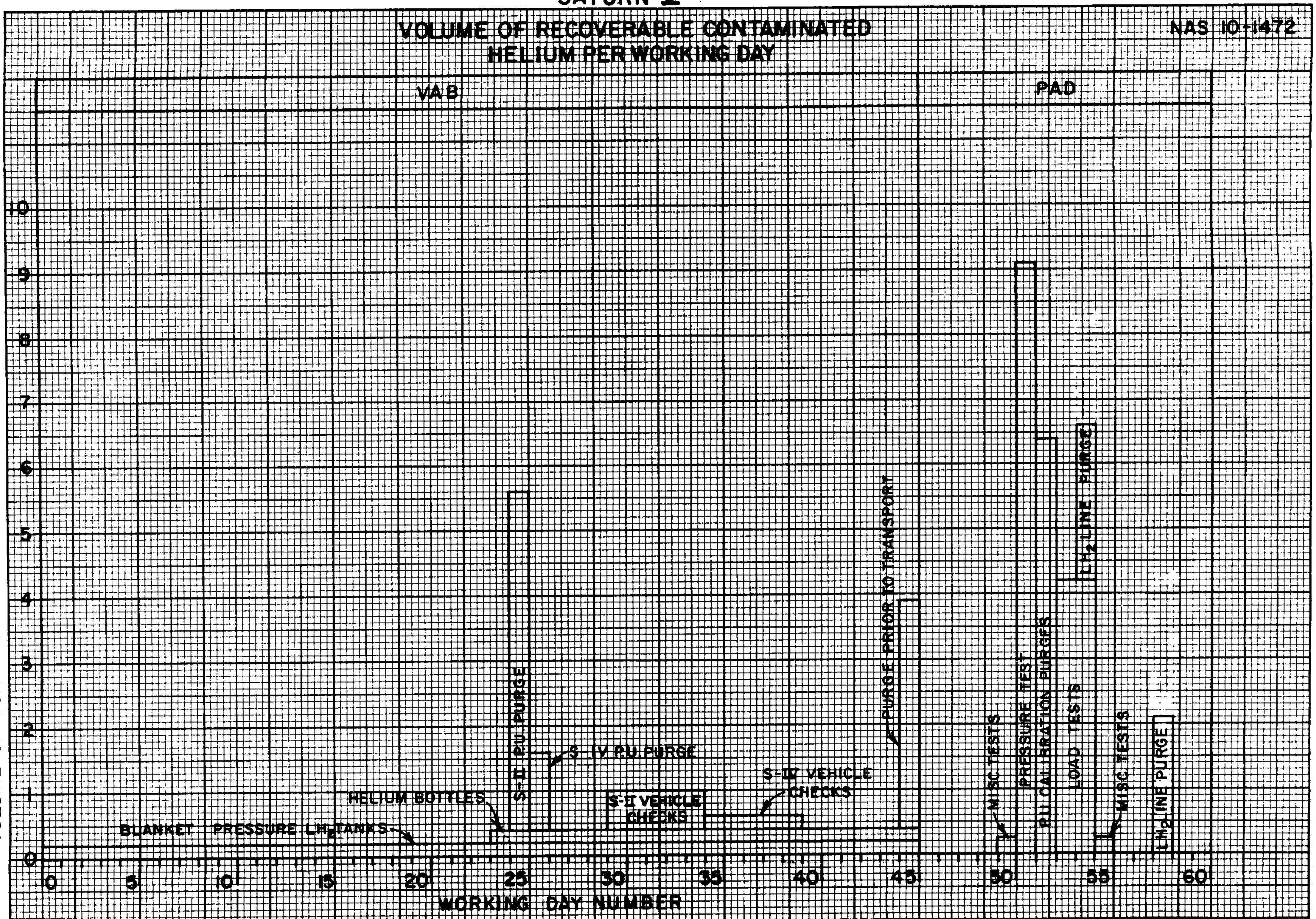
FIGURE 2

SATURN V

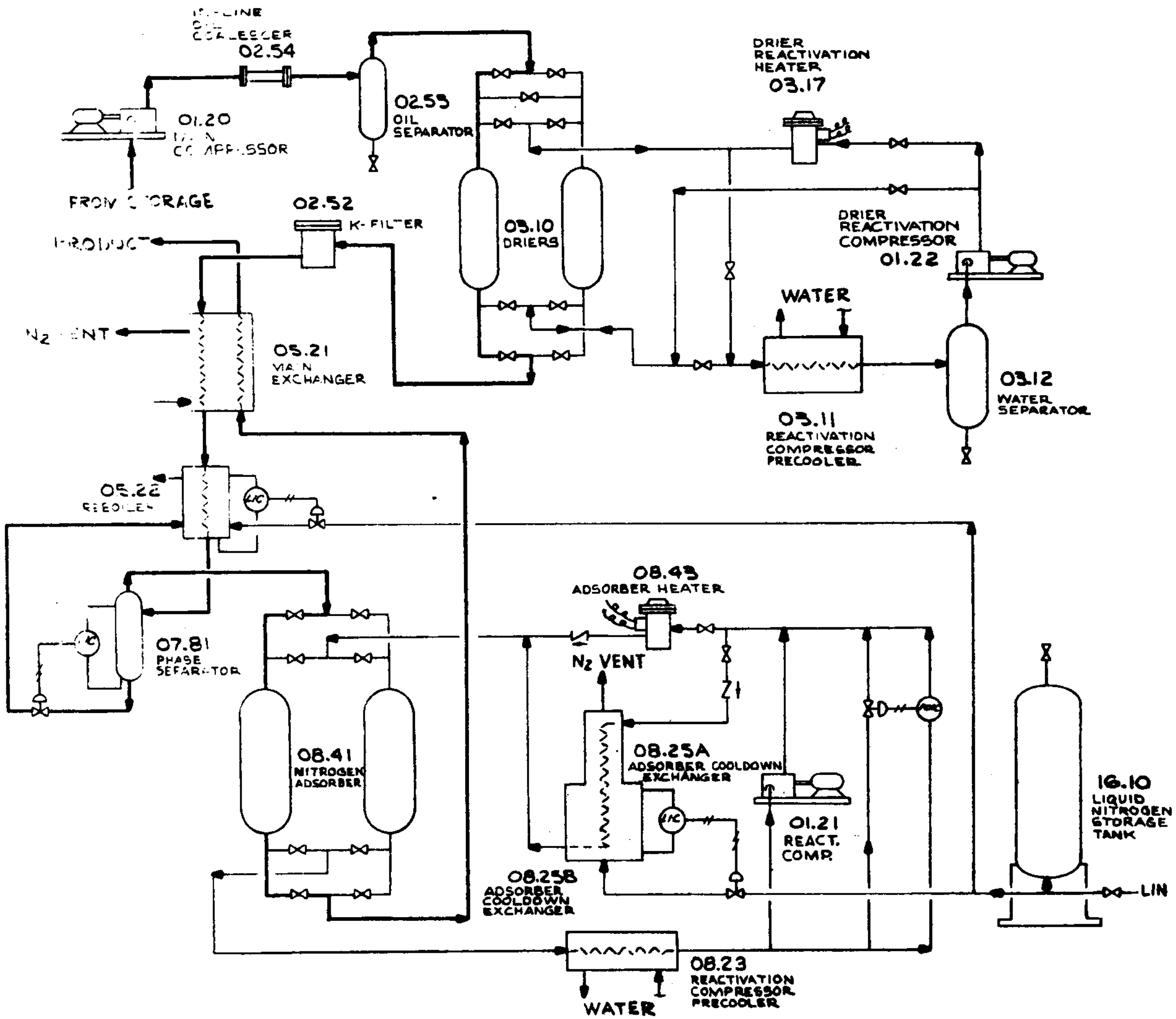


REV. NO. I
11-17-64

FIGURE 3
SATURN V



REV. NO.1
11-17-64



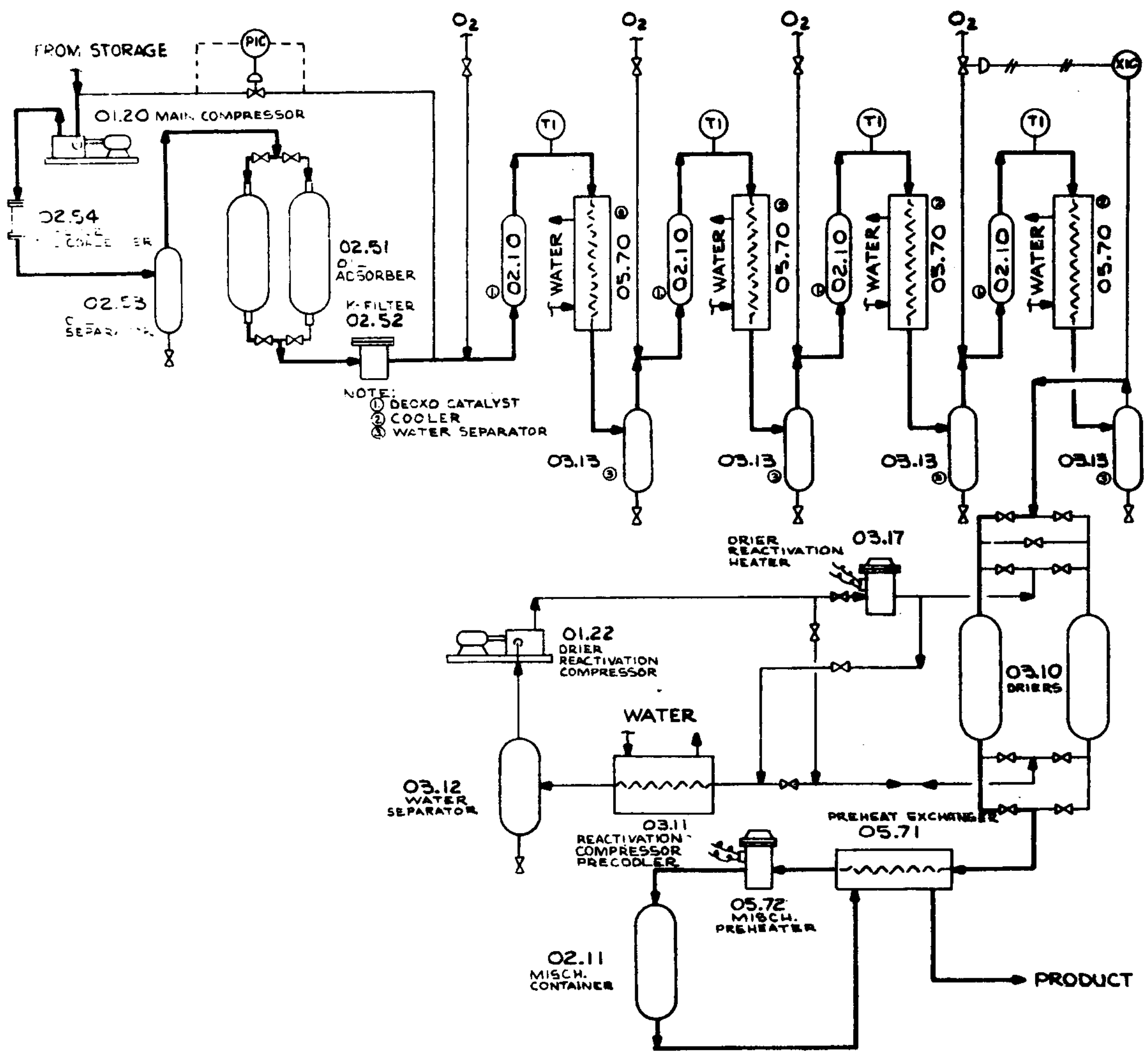
LEGEND

01.20	Main Compressor
01.21	Reactivation Compressor
01.22	Drier Reactivation Compressor
02.52	K-Filter
02.53	Oil Separator
02.54	In-Line Oil Coalescer
03.10	Drier
03.11	Reactivation Compressor Precooler
03.12	Water Separator
03.17	Drier Reactivation Heater
05.21	Main Exchanger
05.22	Reboiler
07.81	Phase Separator
08.23	Reactivation Compressor Preheater
08.25A&B	Adsorber Cooldown Exchanger
08.41	Nitrogen Adsorber
08.43	Adsorber Heater
16.10	Liquid Nitrogen Storage Tank
LIC	Level Indicator Controller
PDIC	Pressure Differential Indicator Controller

HELIUM PURIFICATION EQUIPMENT
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165

CASE I & IA — FIGURE 4
11-13-64

Air Products and Chemicals Inc.
ALLENTOWN, PENNSYLVANIA, U. S. A.



LEGEND

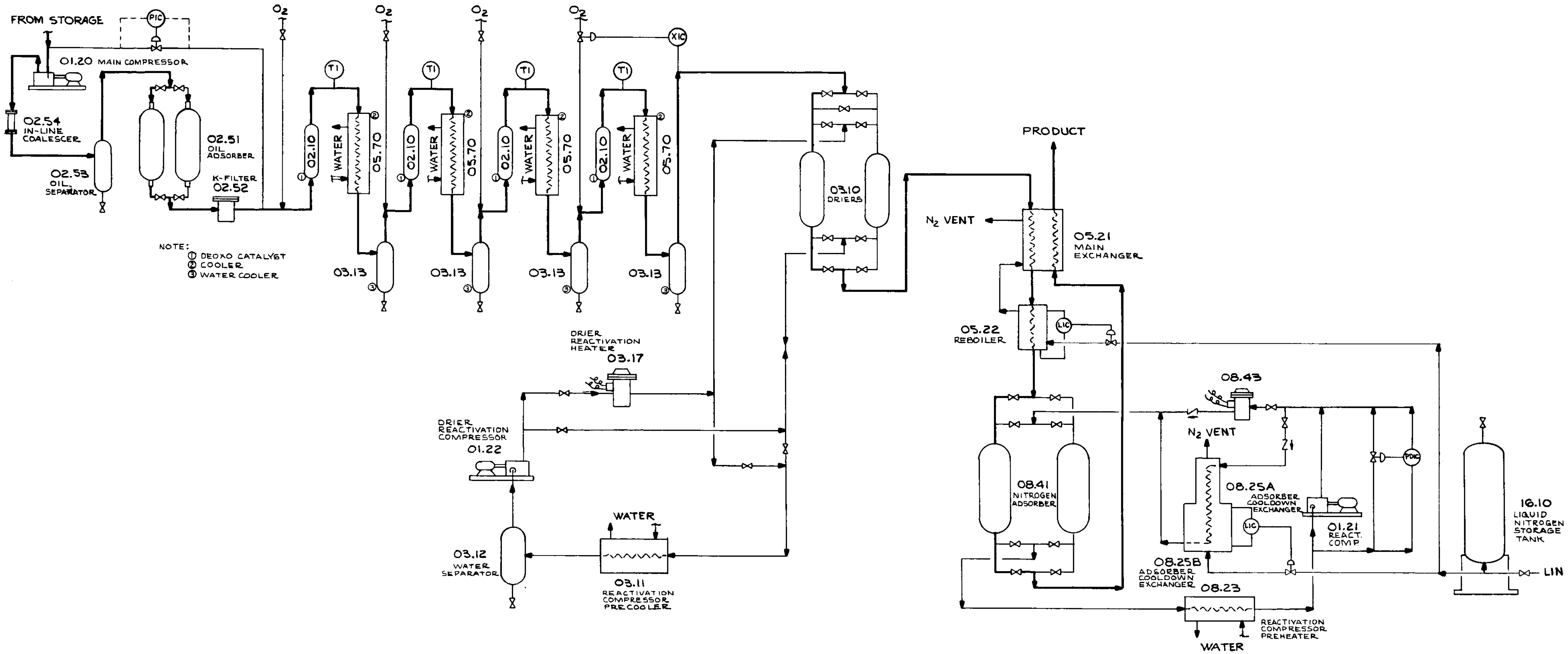
01.20	Main Compressor
01.22	Drier Reactivation Compressor
02.10	Deoxo Catalyst
02.11	Misch. Container
02.51	Oil Adsorber
02.52	K-Filter
02.53	Oil Separator
02.54	In-Line Oil Coalescer
03.10	Drier
03.11	Reactivation Compressor Precooler
03.12	Water Separator
03.13	Water Separator
03.17	Drier Reactivation Heater
05.70	Cooler
05.71	Preheat Exchanger
05.72	Misch. Preheater
PIC	Pressure Indicator Controller
TI	Temperature Indicator
XIC	Concentration Indicator Controller

HELIUM PURIFICATION EQUIPMENT
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165

CASE II

FIGURE 5
11-13-64

Air Products and Chemicals Inc.
ALLENTOWN, PENNSYLVANIA, U. S. A.



LEGEND

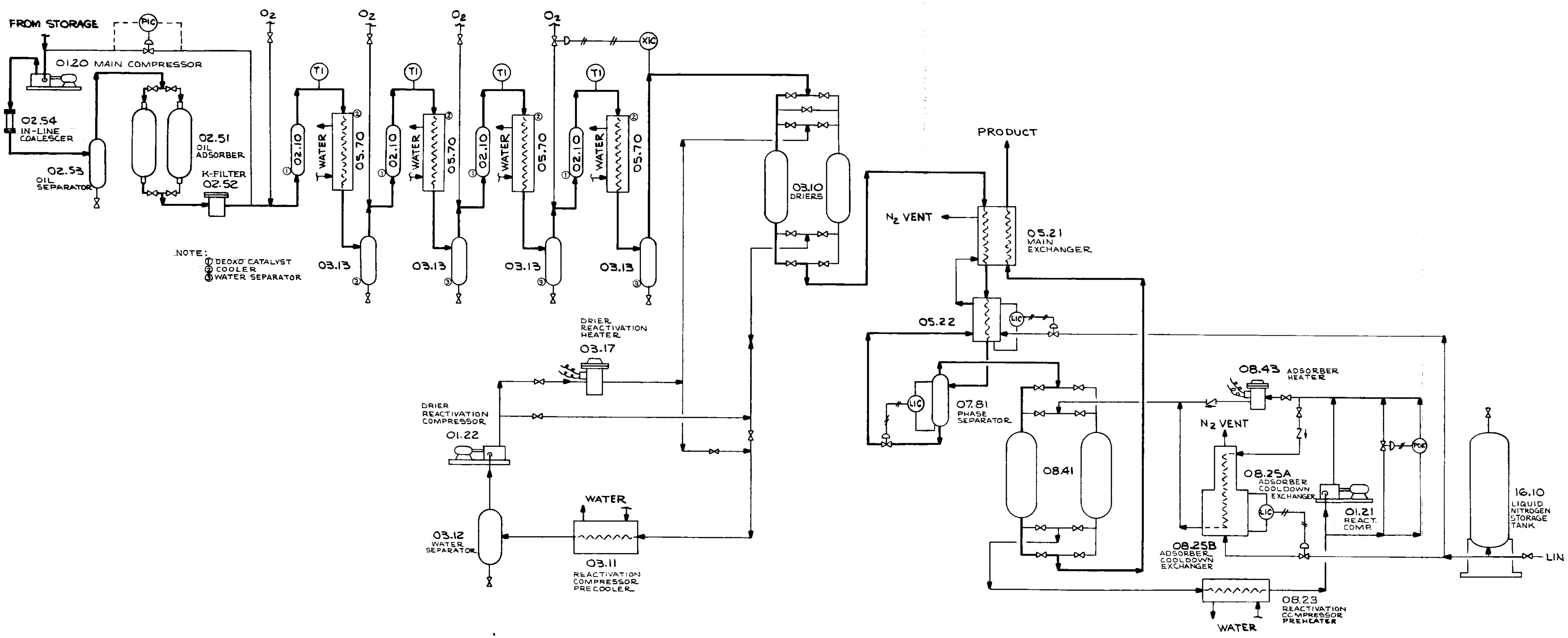
01.20	Main Compressor
01.21	Reactivation Compressor
01.22	Drier Reactivation Compressor
02.10	Deoxo Catalyst
02.51	Oil Adsorber
02.52	K-Filter
02.53	Oil Separator
02.54	In-Line Oil Coalescer
03.10	Drier
03.11	Reactivation Compressor Precooler
03.12	Water Separator
03.13	Water Separator
03.17	Drier Reactivation Heater
05.21	Main Exchanger
05.22	Reboiler
05.70	Cooler
08.23	Reactivation Compressor Preheater
08.25A&B	Adsorber Cooldown Exchanger
08.41	Nitrogen Adsorber
08.43	Adsorber Heater
16.10	Liquid Nitrogen Storage Tank
LIC	Level Indicator Controller
PDIC	Pressure Differential Indicator Controller
PIC	Pressure Indicator Controller
TI	Temperature Indicator
XIC	Concentration Indicator Controller

HELIUM PURIFICATION EQUIPMENT
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165

CASE III

FIGURE 6
11-13-64

Air Products and Chemicals Inc.
ALLENTOWN, PENNSYLVANIA, U. S. A.



LEGEND

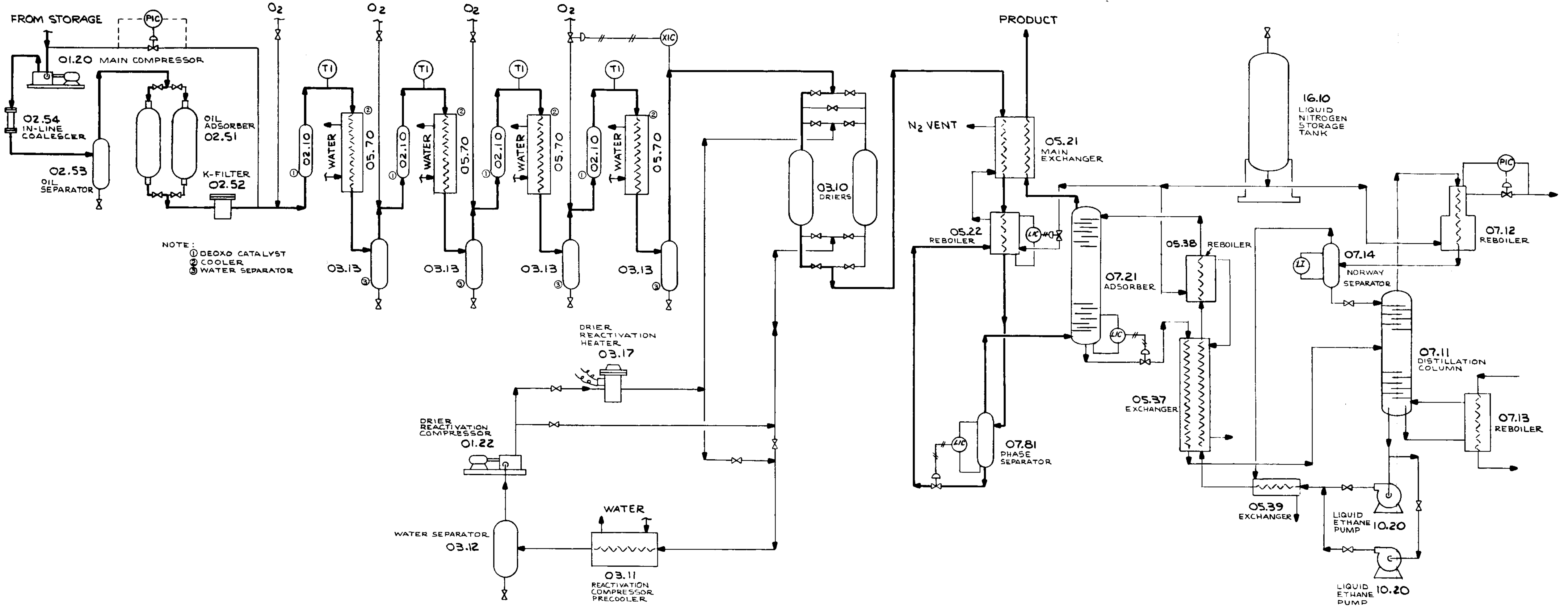
01.20	Main Compressor
01.21	Reactivation Compressor
01.22	Drier Reactivation Compressor
02.10	Deoxo Catalyst
02.51	Oil Adsorber
02.52	K-Filter
02.53	Oil Separator
02.54	In-Line Coalescer
03.10	Drier
03.11	Reactivation Compressor Precooler
03.12	Water Separator
03.13	Water Separator
03.17	Drier Reactivation Heater
05.21	Main Exchanger
05.22	Reboiler
05.70	Cooler
07.81	Phase Separator
08.23	Reactivation Compressor Preheater
08.25A&B	Adsorber Cooldown Exchanger
08.41	Nitrogen Adsorber
08.43	Adsorber Heater
16.10	Liquid Nitrogen Storage Tank
LIC	Level Indicator Controller
PDIC	Pressure Differential Indicator Controller
PIC	Pressure Indicator Controller
TI	Temperature Indicator
XIC	Cocentration Indicator Controller

HELIUM PURIFICATION EQUIPMENT
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165

CASE IV

FIGURE 7
11-13-64

Air Products and Chemicals Inc.
ALLENTOWN, PENNSYLVANIA, U. S. A.



LEGEND

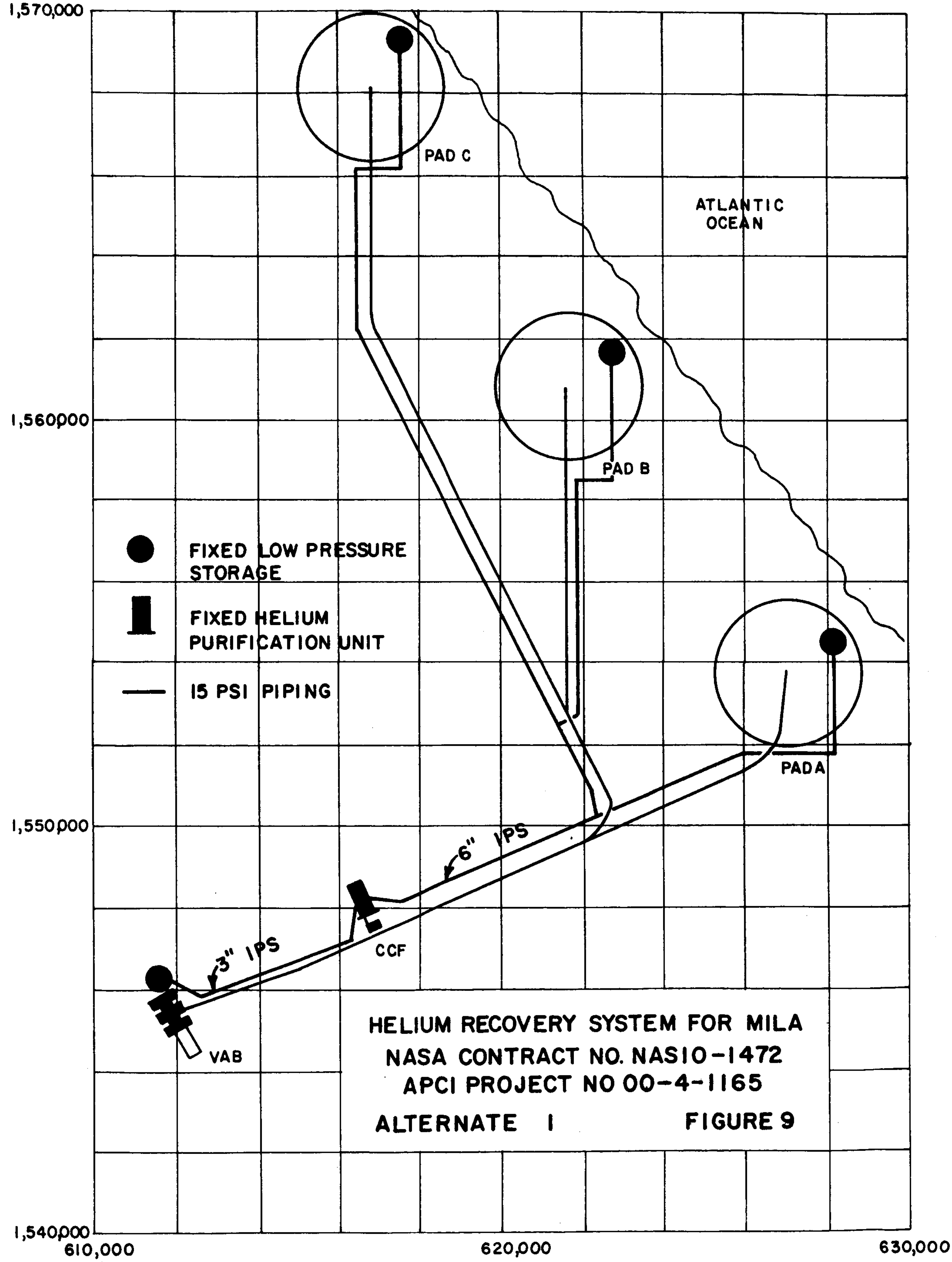
01.20	Main Compressor
01.22	Drier Reactivation Compressor
02.10	Deoxo Catalyst
02.51	Oil Adsorber
02.52	K-Filter
02.53	Oil Separator
02.54	In-Line Coalescer
03.10	Drier
03.11	Reactivation Compressor Precooler
03.12	Water Separator
03.13	Water Separator
03.17	Drier Reactivation Heater
05.21	Main Exchanger
05.22	Reboiler
05.37	Exchanger
05.38	Reboiler
08.39	Exchanger
07.11	Distillation Column
07.12	Reboiler
07.13	Reboiler
07.14	Norway Separator
07.21	Absorber
07.81	Phase Separator
10.20	Liquid Ethane Pump
16.10	Liquid Nitrogen Storage Tank
LI	Level Indicator
LIC	Level Indicator Controller
PIC	Pressure Indicator Controller
TI	Temperature Indicator
XIC	Concentration Indicator Controller

HELIUM PURIFICATION EQUIPMENT
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165

CASE V

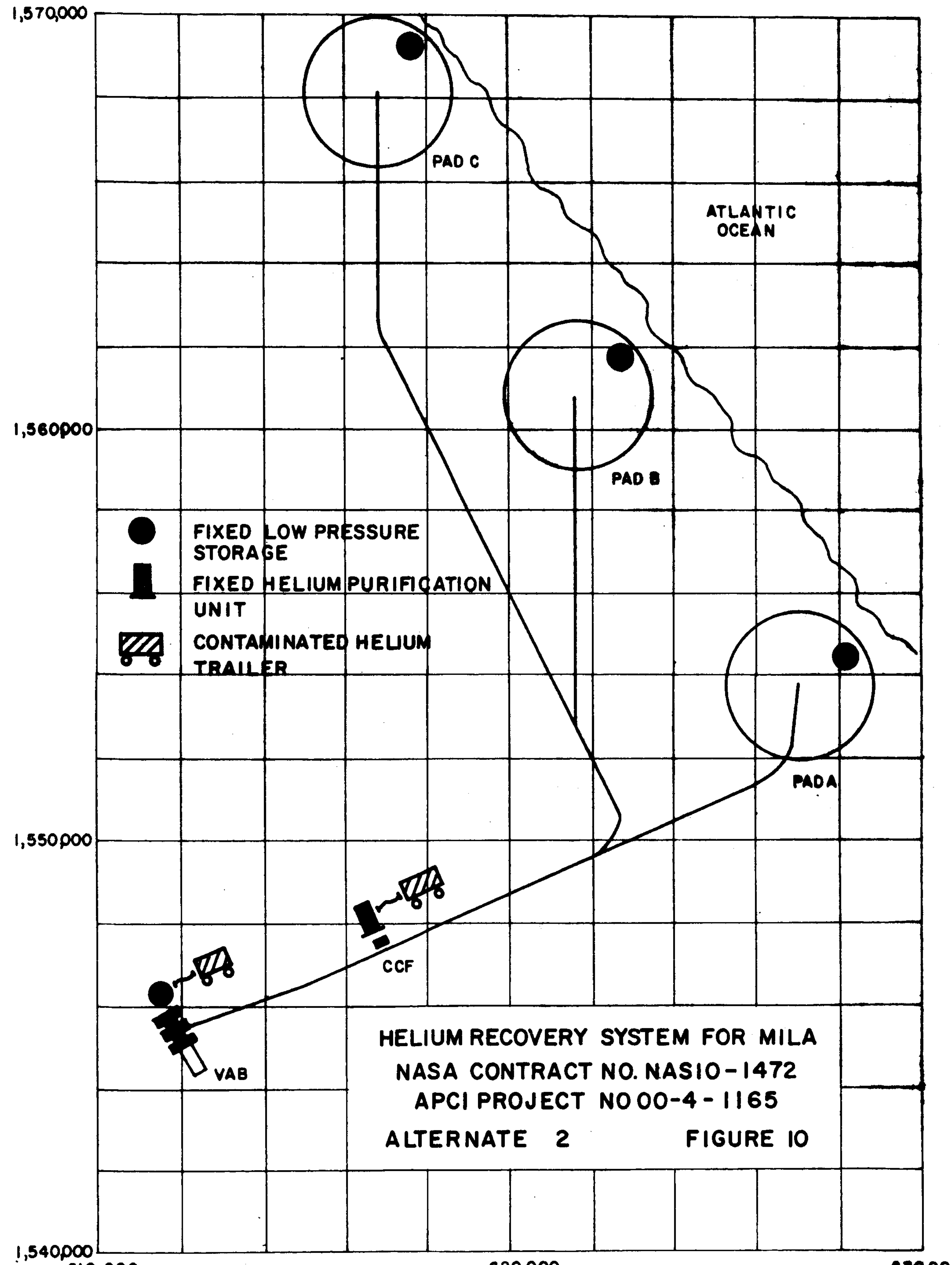
FIGURE 8
11-13-64

Air Products and Chemicals INC.
ALLENTOWN, PENNSYLVANIA, U. S. A.

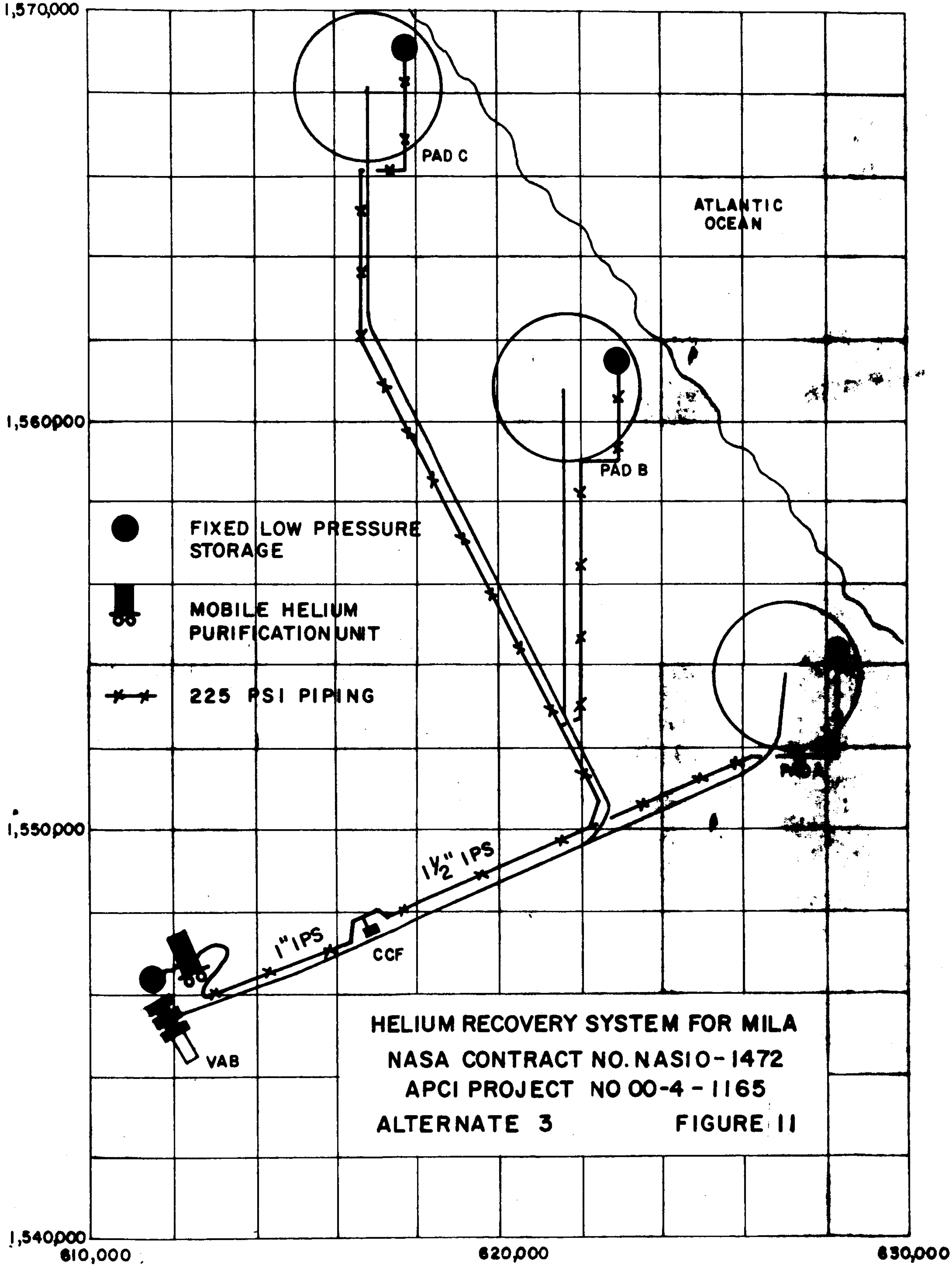


HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO 00-4-1165

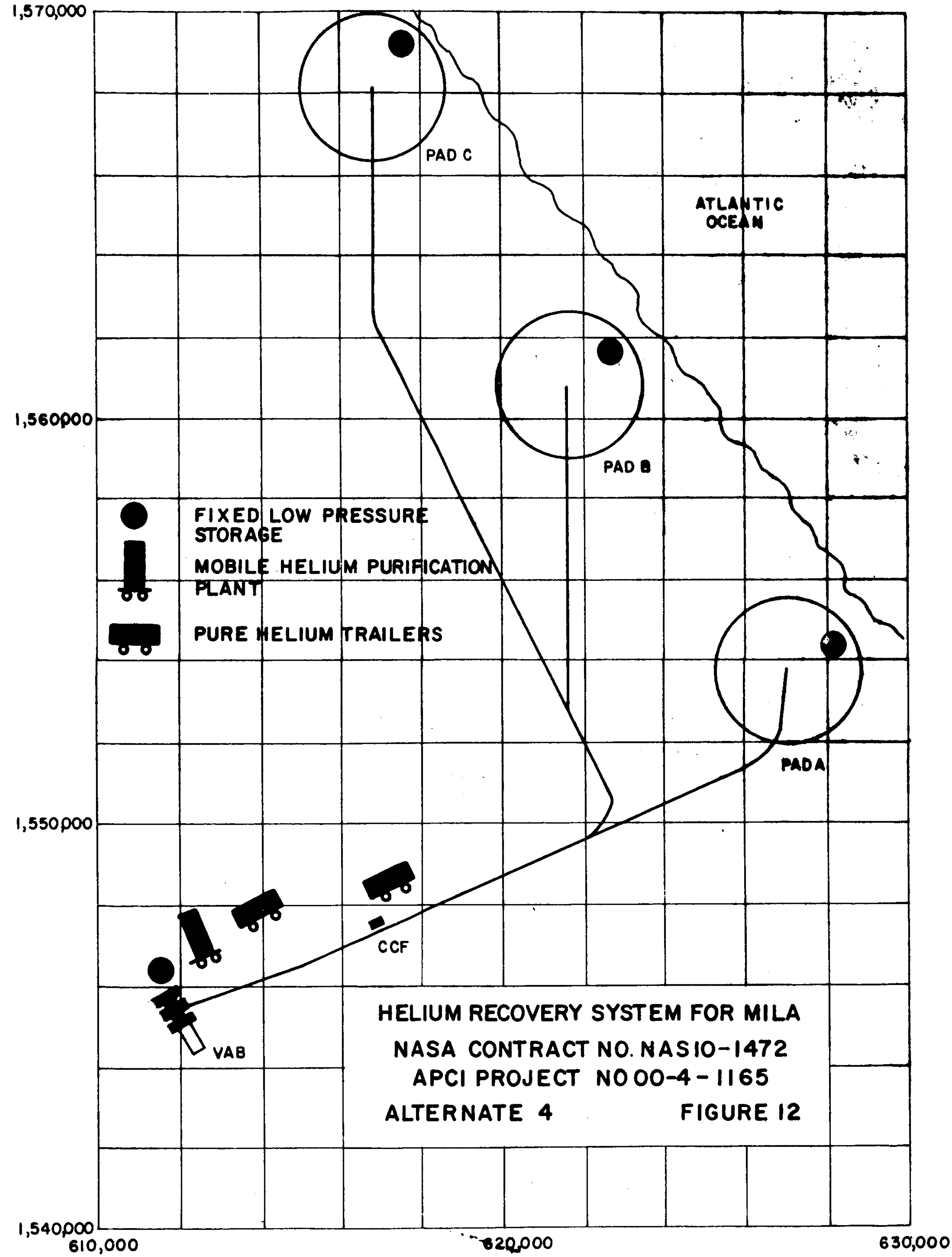
ALTERNATE I FIGURE 9

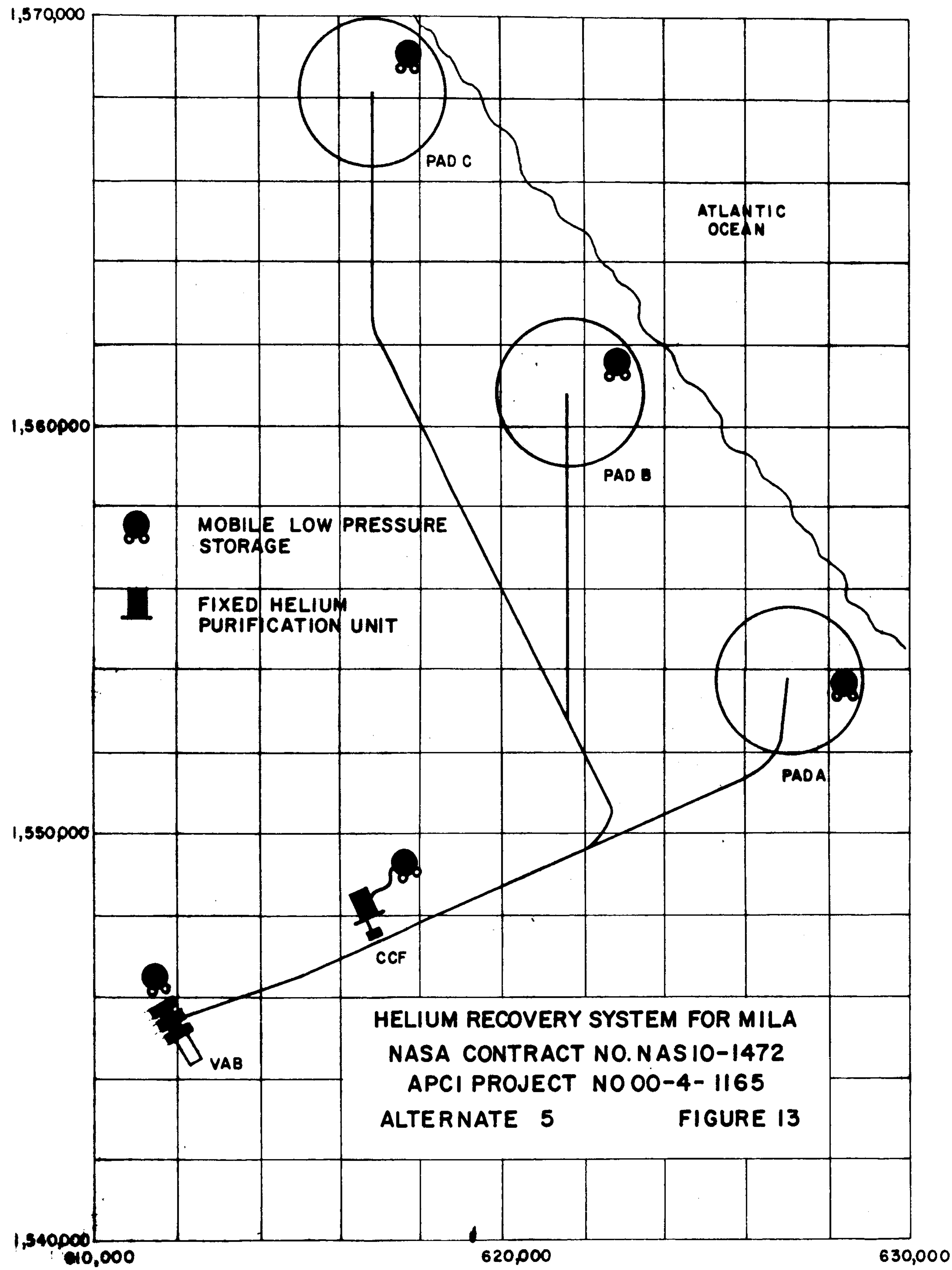


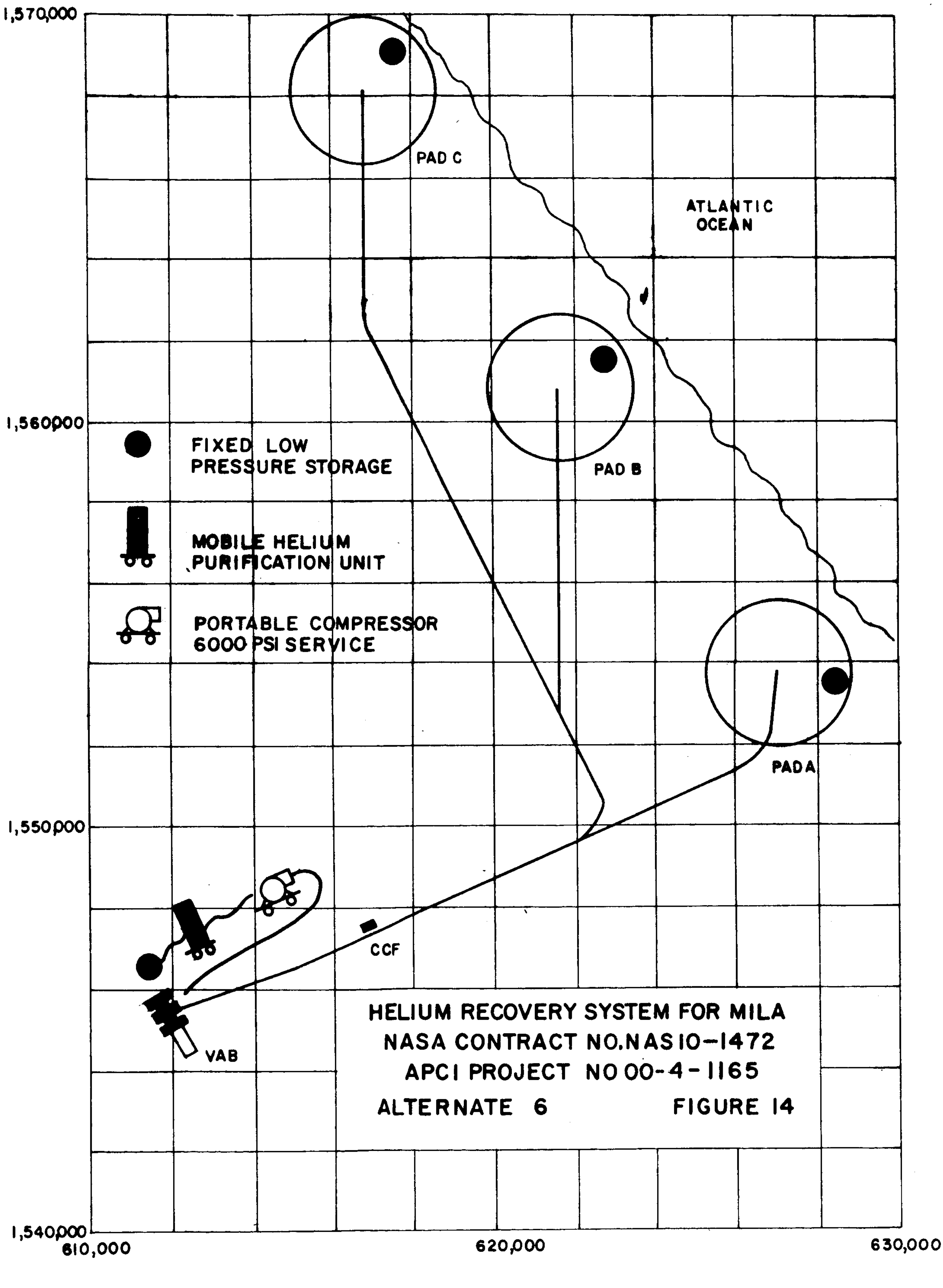
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO 00-4-1165
ALTERNATE 2 FIGURE 10



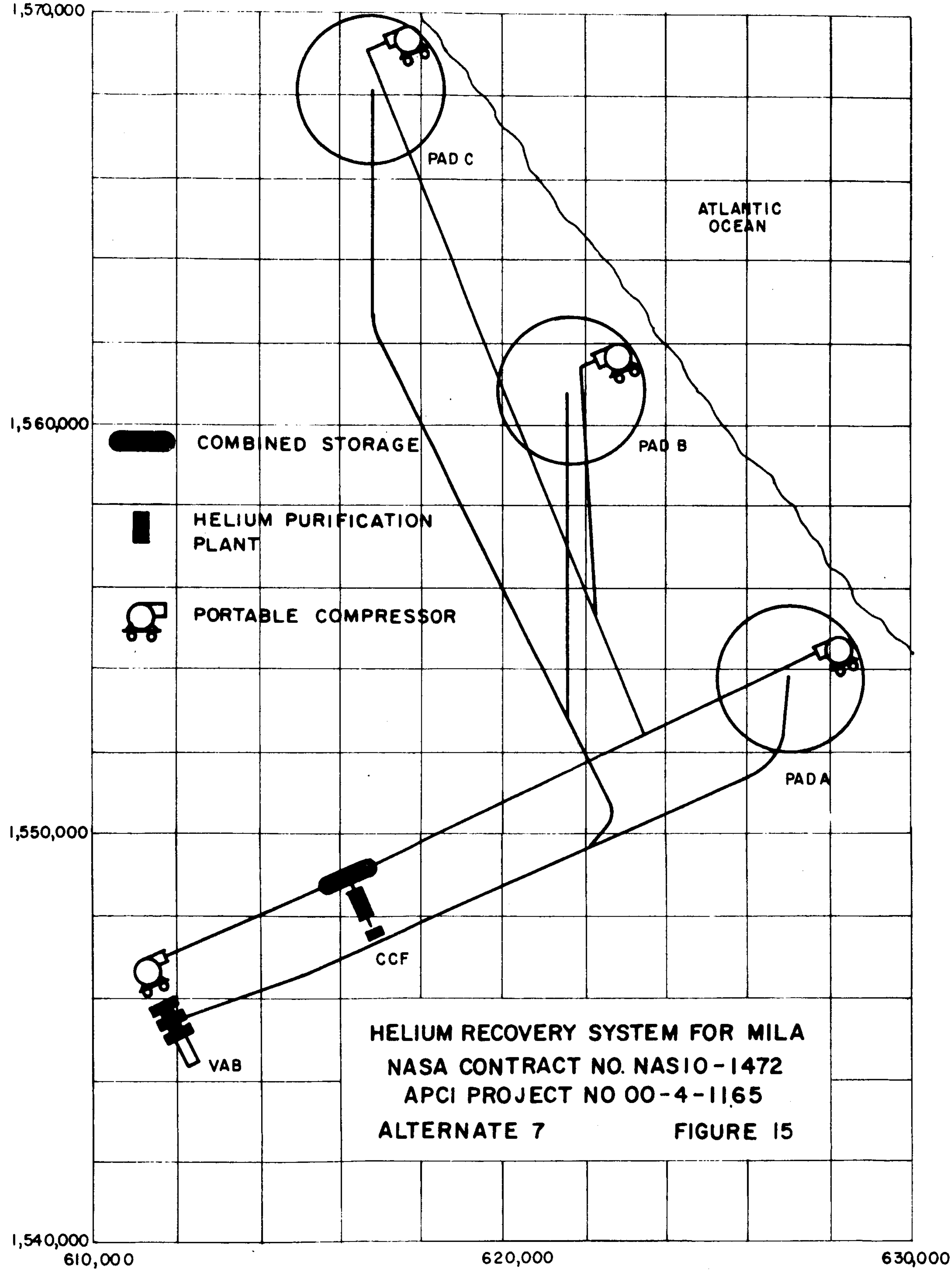
1,570,000
1,560,000
1,550,000
1,540,000
610,000
620,000
630,000
PAD C
PAD B
PAD A
ATLANTIC OCEAN
FIXED LOW PRESSURE STORAGE
MOBILE HELIUM PURIFICATION UNIT
225 PSI PIPING
1 1/2" IPS
1" IPS
CCF
VAB
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO 00-4-1165
ALTERNATE 3
FIGURE 11


1,570,000
1,560,000
1,550,000
1,540,000
610,000
620,000
630,000
PAD C
PAD B
PAD A
ATLANTIC OCEAN
FIXED LOW PRESSURE STORAGE
MOBILE HELIUM PURIFICATION PLANT
PURE HELIUM TRAILERS
CCF
VAB
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO 00-4-1165
ALTERNATE 4
FIGURE 12


1,570,000
1,560,000
1,550,000
1,540,000
610,000
620,000
630,000
PAD C
PAD B
PAD A
ATLANTIC OCEAN
MOBILE LOW PRESSURE STORAGE
FIXED HELIUM PURIFICATION UNIT
CCF
VAB
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS 10-1472
APCI PROJECT NO 00-4-1165
ALTERNATE 5
FIGURE 13

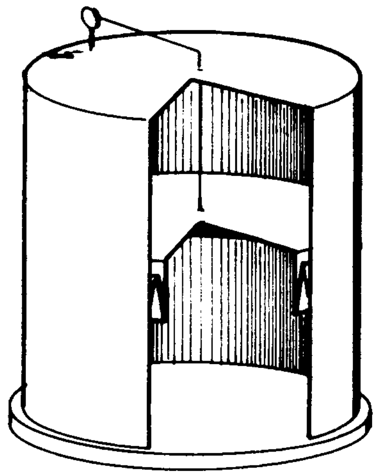


HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO.NAS10-1472
APCI PROJECT NO 00-4-1165
ALTERNATE 6 FIGURE 14

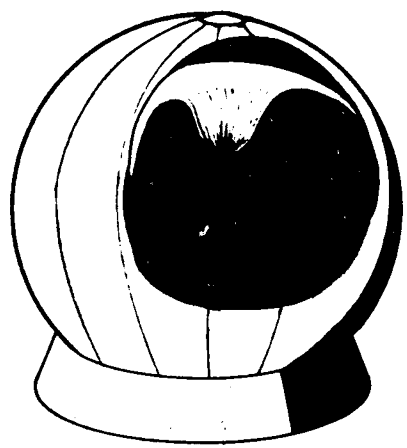


HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO 00-4-1165
ALTERNATE 7 FIGURE 15

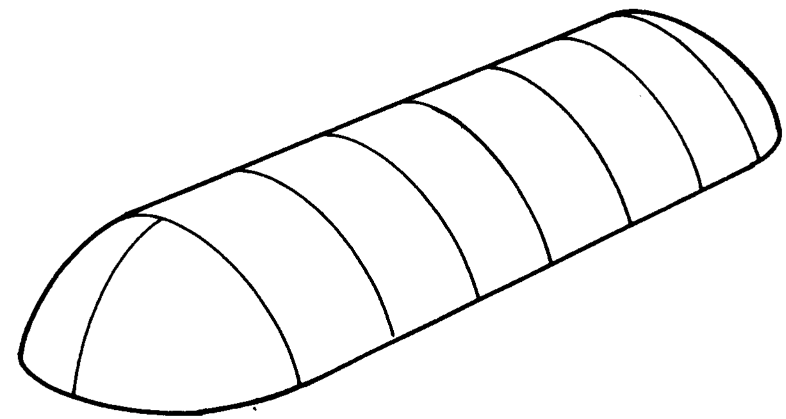
FIGURE 16
LOW PRESSURE STORAGE CONTAINER



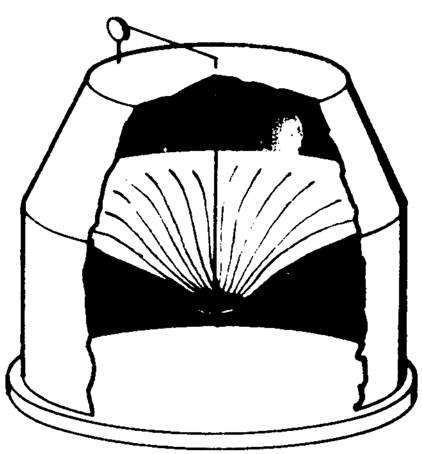
GATC



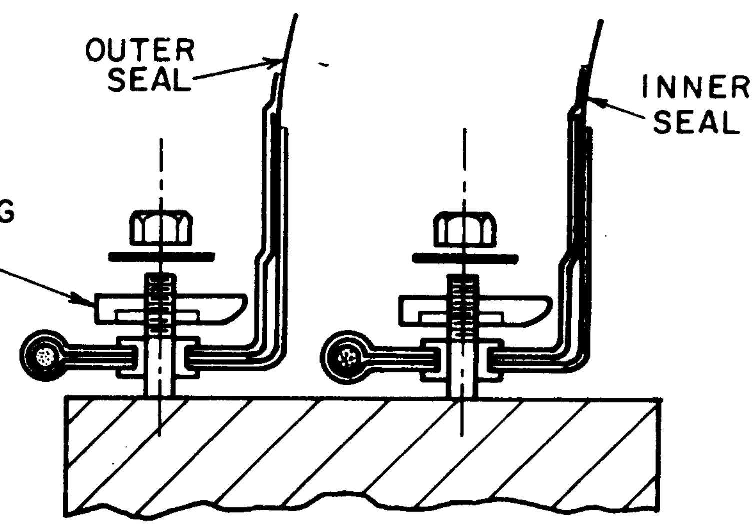
GOODYEAR
BIRDAIR



VIRON



CB&I



TYPICAL BASE SEAL

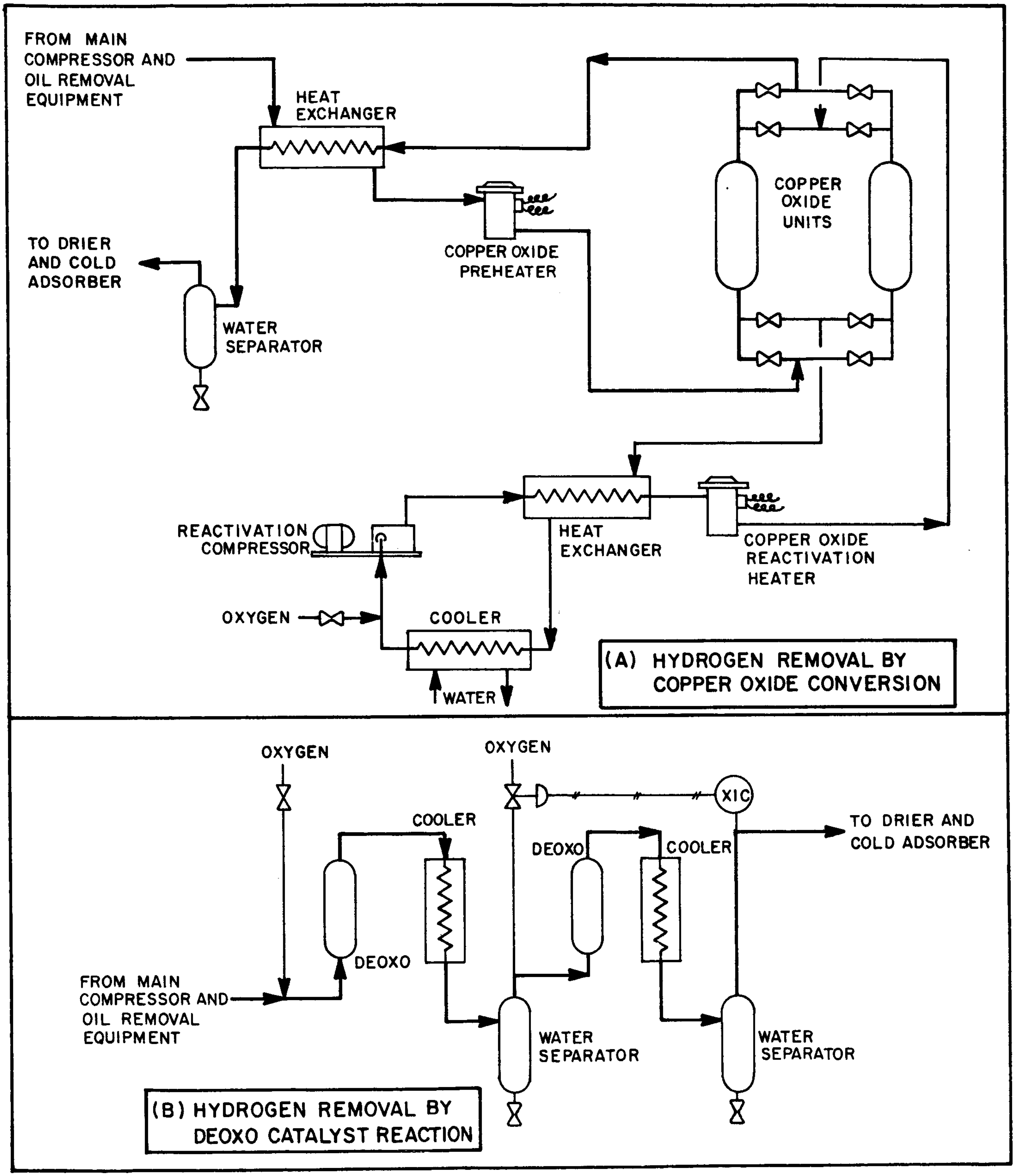
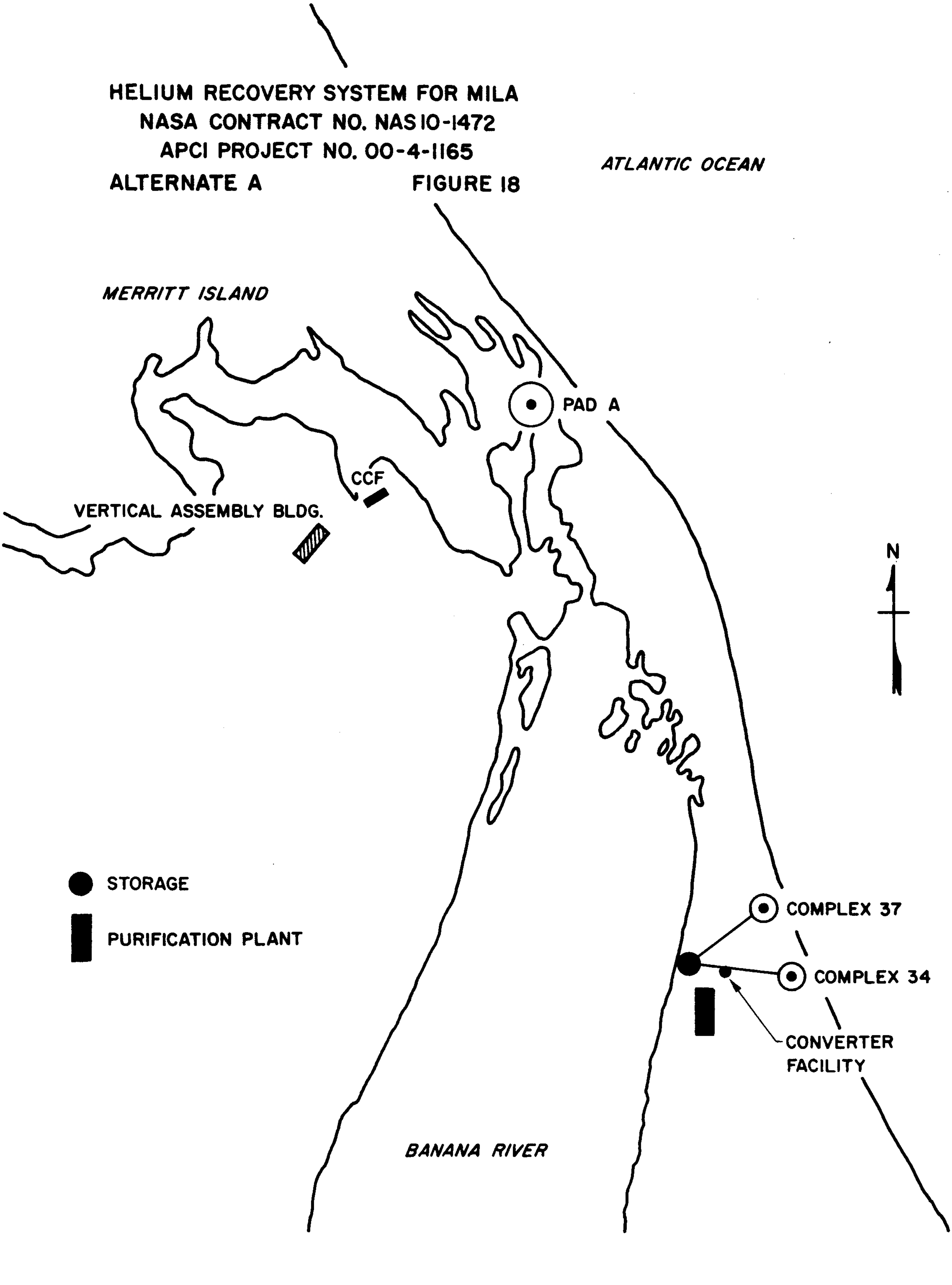
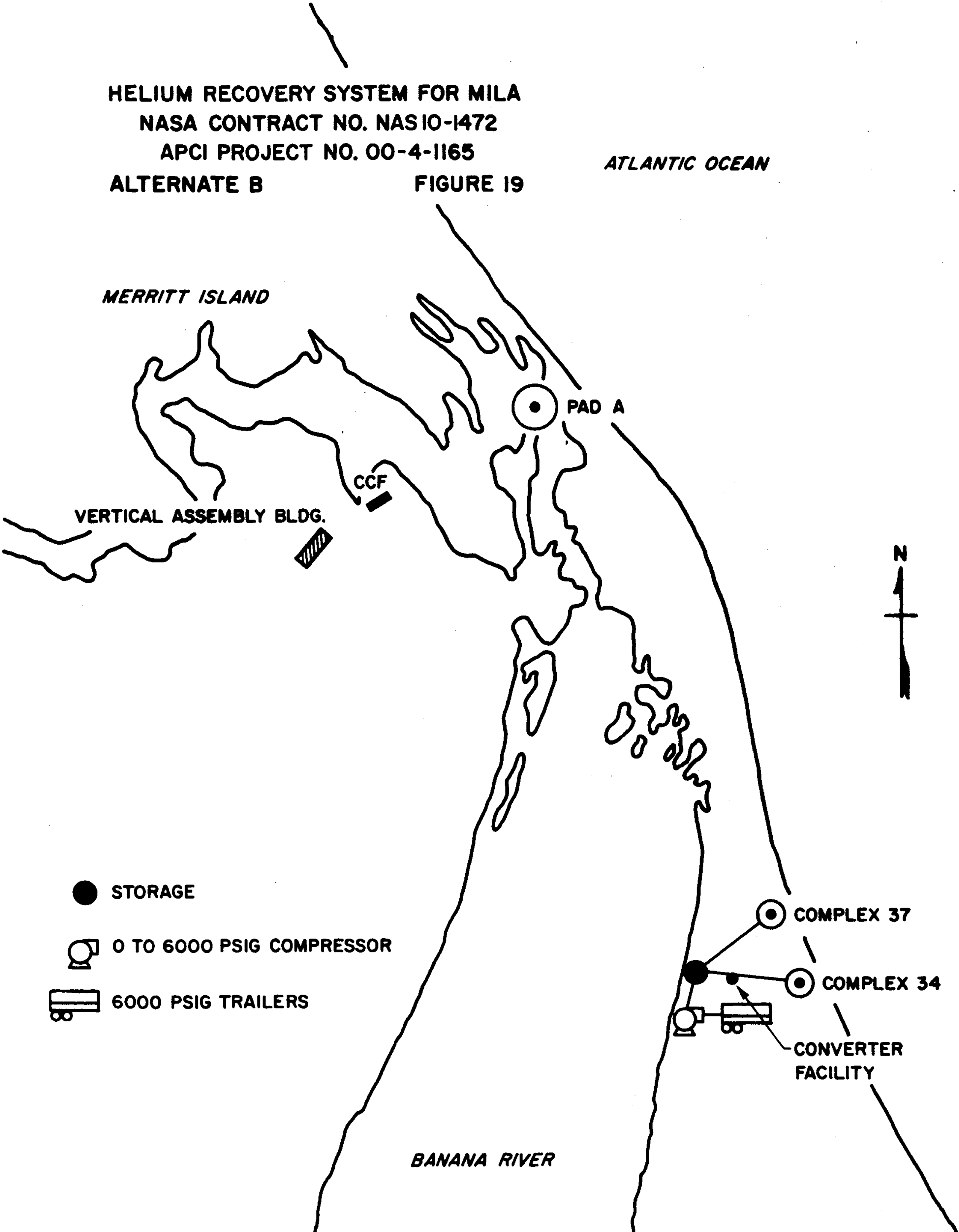


FIGURE 17 COMPARISON OF EQUIPMENT REQUIREMENTS FOR HYDROGEN REMOVAL BY (A) COPPER OXIDE CONVERSION AND (B) DEOXO CATALYST REACTION

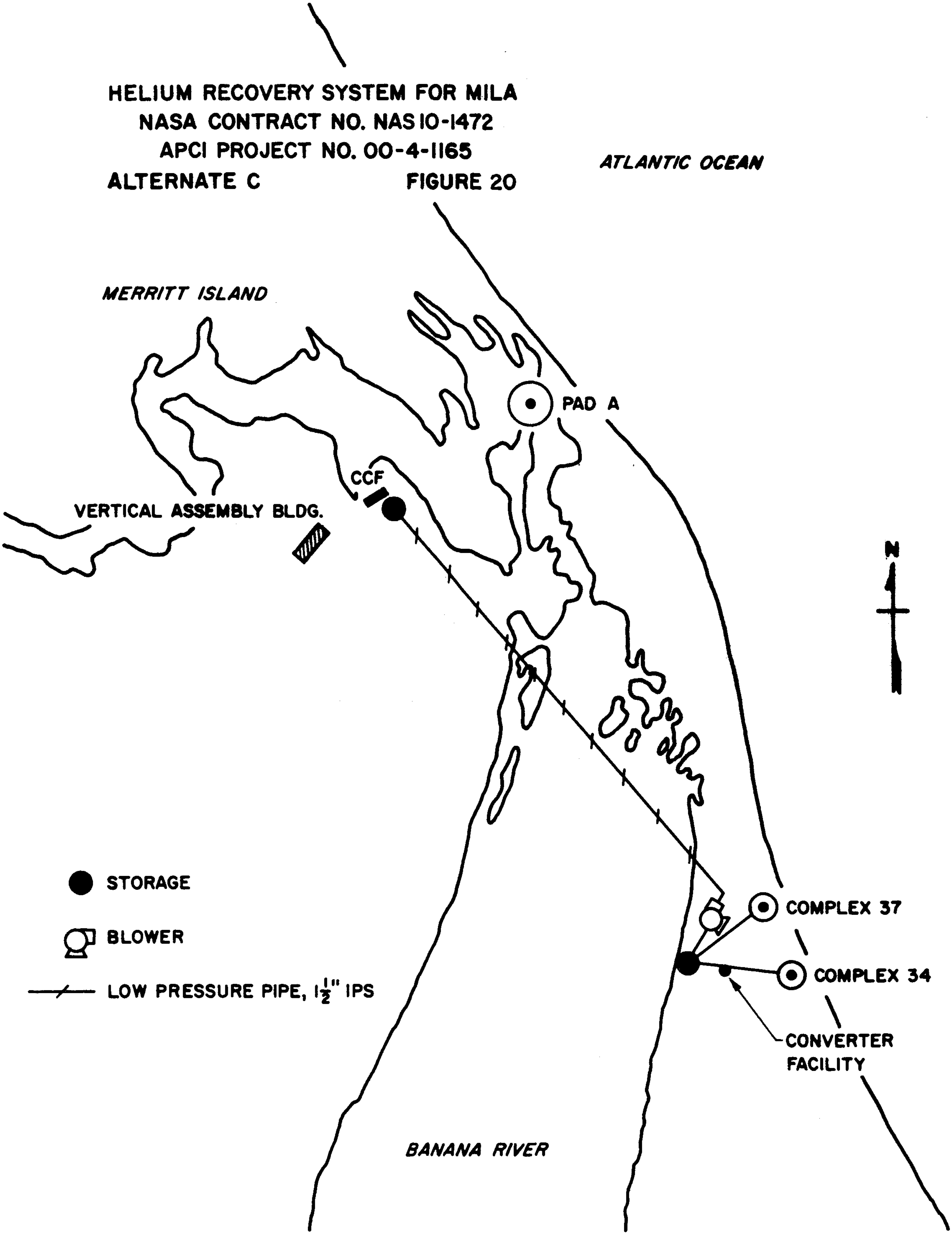

HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165
ALTERNATE A
FIGURE 18
ATLANTIC OCEAN
MERRITT ISLAND
PAD A
CCF
VERTICAL ASSEMBLY BLDG.
N
STORAGE
PURIFICATION PLANT
COMPLEX 37
COMPLEX 34
CONVERTER FACILITY
BANANA RIVER

HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS 10-1472
APCI PROJECT NO. 00-4-1165
ALTERNATE B

FIGURE 19



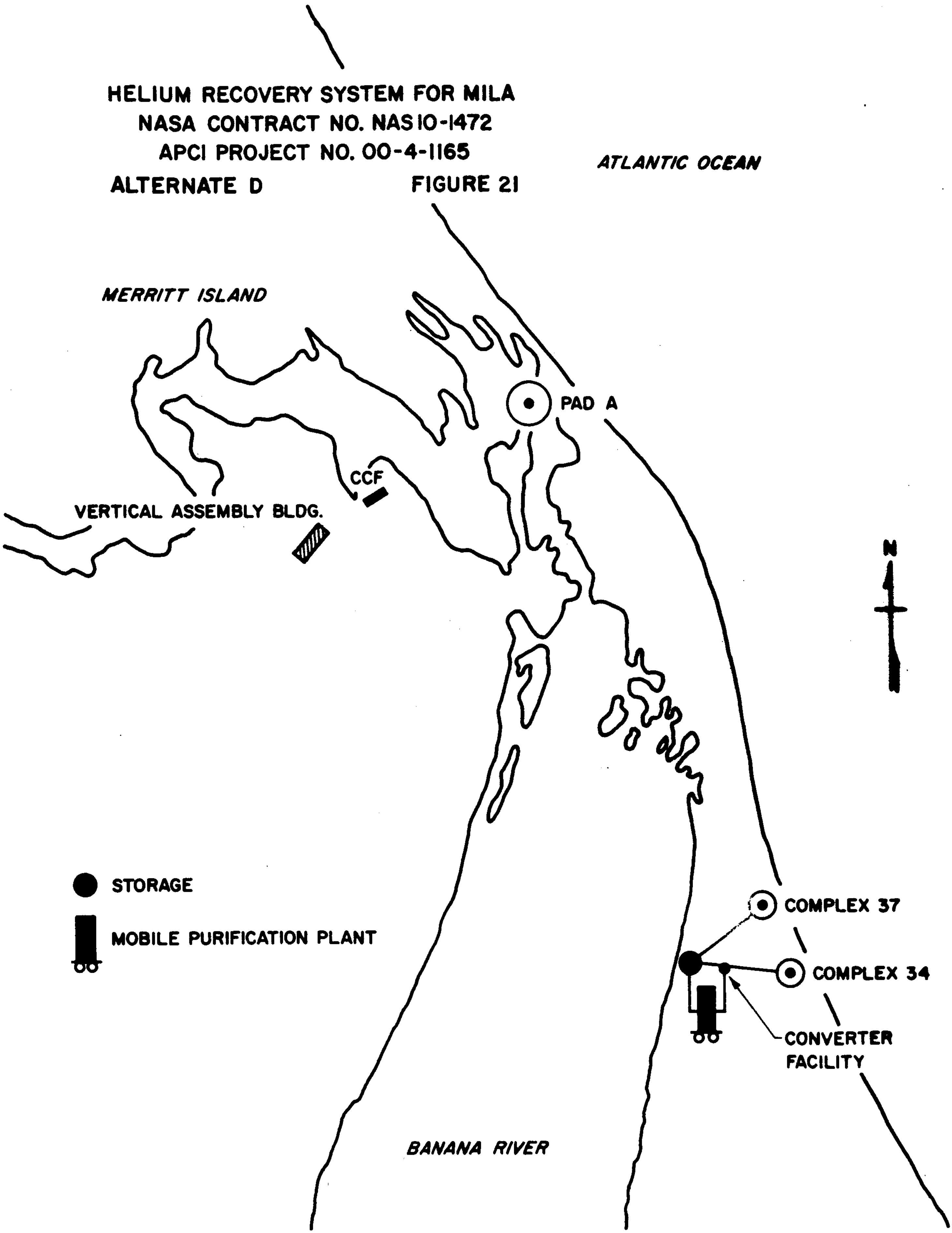
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS 10-1472
APCI PROJECT NO. 00-4-1165
ALTERNATE C FIGURE 20

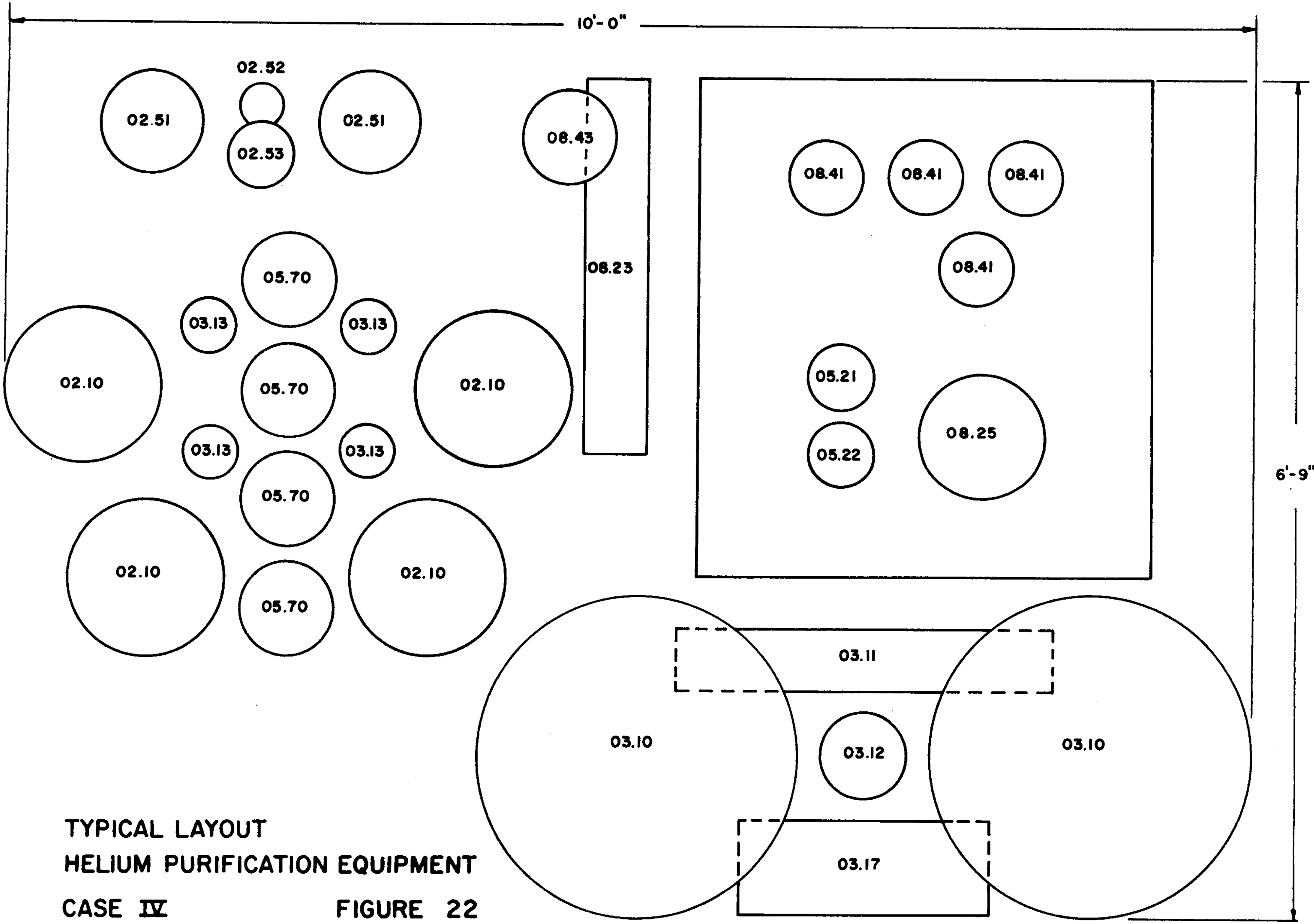


HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165

ALTERNATE D

FIGURE 21





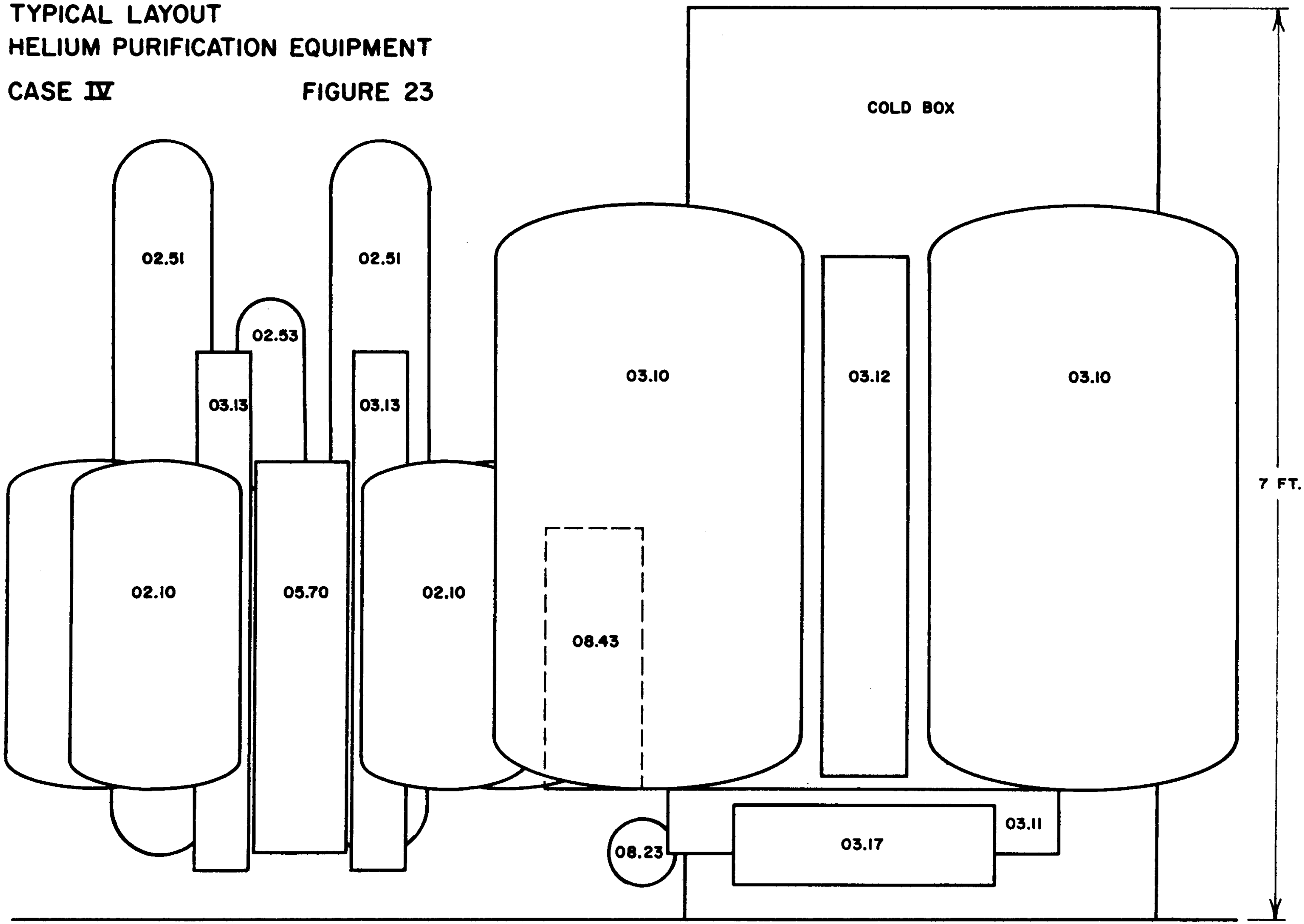
TYPICAL LAYOUT
HELIUM PURIFICATION EQUIPMENT

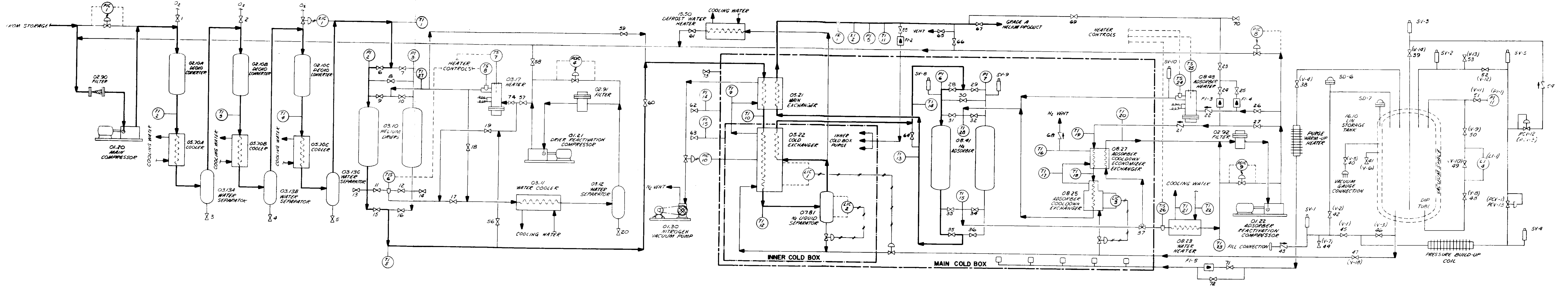
CASE IV FIGURE 22

TYPICAL LAYOUT
HELIUM PURIFICATION EQUIPMENT

CASE IV

FIGURE 23



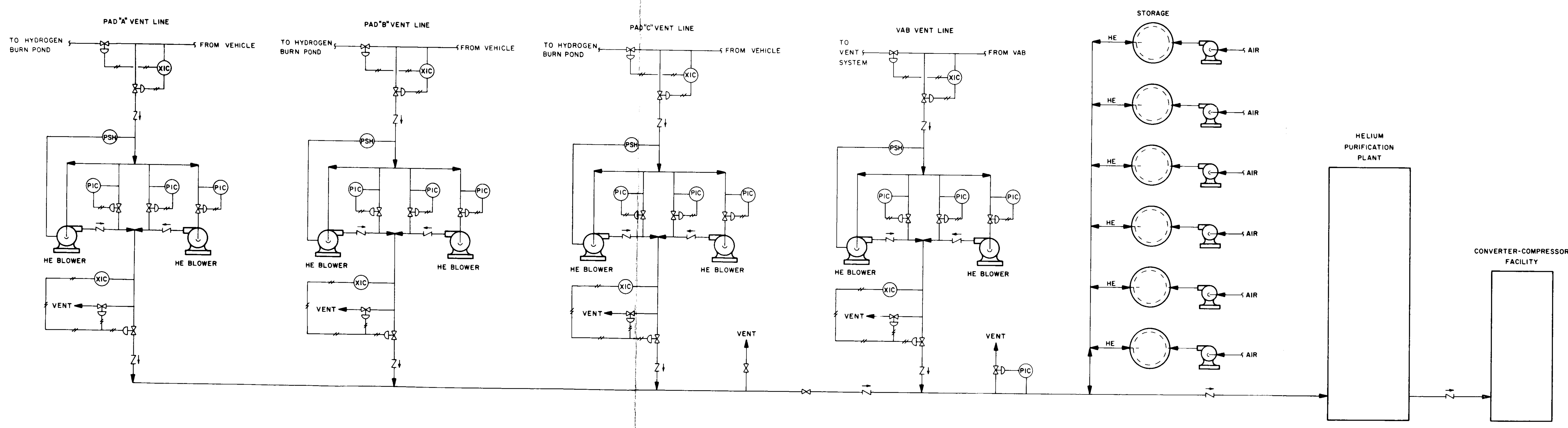


LEGEND

01.20	Main Compressor
01.21	Drier Reactivation Compressor
01.22	Adsorber Reactivation Compressor
01.30	Nitrogen Vacuum Pump
02.10	Deoxo Converter
02.90	Filter
02.91	Filter
02.92	Filter
03.10	Drier
03.11	Water Cooler
03.12	Water Separator
03.13	Water Separator
03.17	Heater
05.21	Main Exchanger
05.22	Cold Exchanger
05.70	Cooler
07.81	Nitrogen Liquid Separator
08.23	Water Heater
08.25	Adsorber Cooldown Exchanger
08.27	Adsorber Cooldown Economizer Exchanger
08.41	Nitrogen Adsorber
08.43	Adsorber Heater
15.50	Defrost Water Heater
16.10	LIN Storage Tank
FI	Flow Indicator
FR	Flow Recorder
LI	Level Indicator
LIC	Level Indicating Controller
PCV	Pressure Control Valve
PDIC	Pressure Differential Indicating Controller
PIC	Pressure Indicating Control
SD	Safety Disc
SV	Safety Valve
TI	Temperature Indicator
TIS	Temperature Indicating Switch
TS	Temperature Switch
XI	Analyzer Indicator

HELIUM PURIFICATION EQUIPMENT
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 00-4-1165
FIGURE 24

Air Products and Chemicals INC.
ALLENTOWN, PENNSYLVANIA, U. S. A.



PIC Pressure Indicating Controller
PSH Pressure Switch High
XIC Oxygen Hydrogen Analyzer Indicating Controller

HELIUM RECOVERY SYSTEM
DESIGN STUDY OF A
HELIUM RECOVERY SYSTEM FOR MILA
NASA CONTRACT NO. NAS10-1472
APCI PROJECT NO. 0C-4-1165
FIGURE 25

Air Products and Chemicals INC.
ALLENTOWN, PENNSYLVANIA, U. S. A.

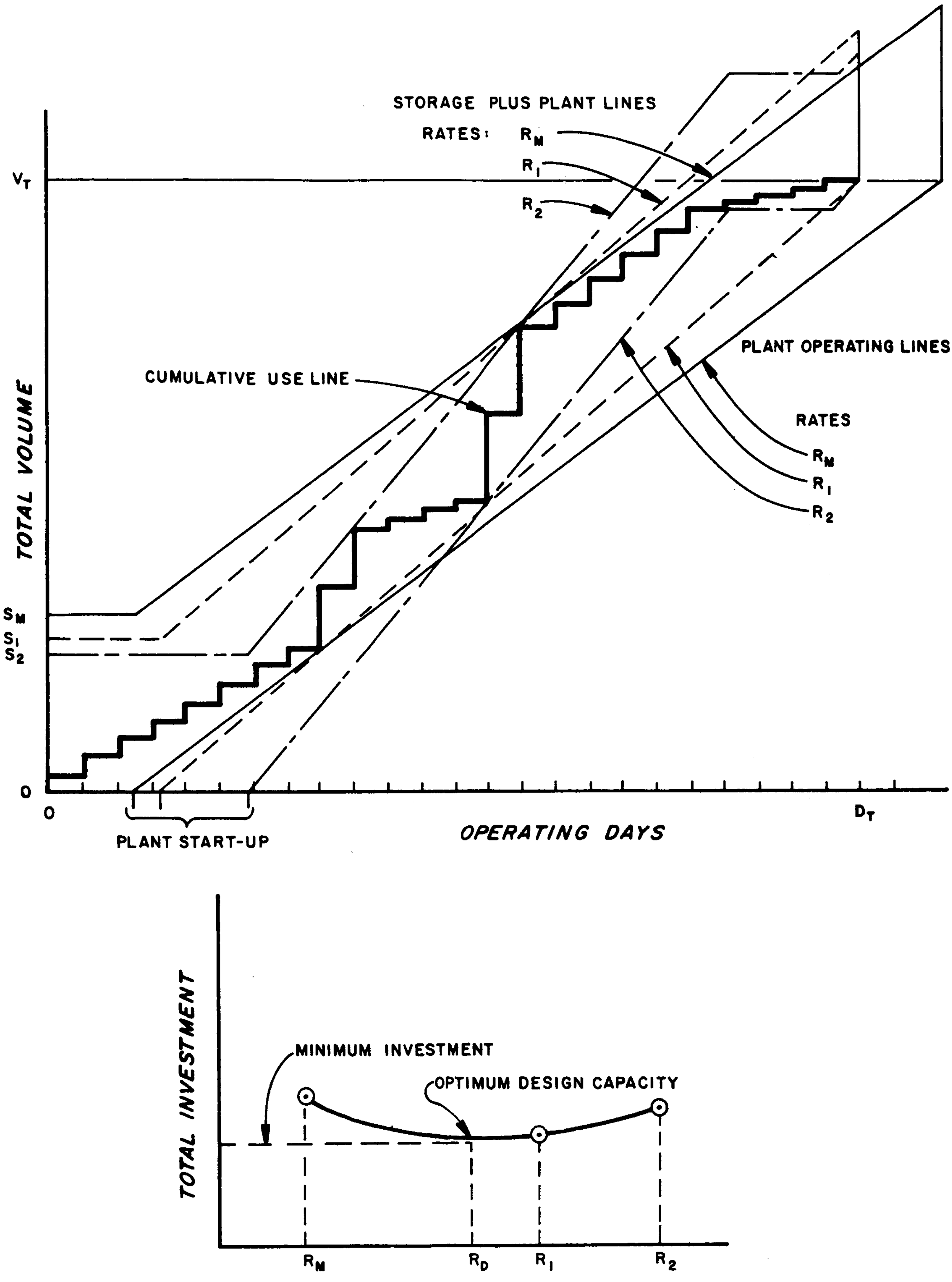


FIGURE 26. OPTIMIZATION OF PLANT CAPACITY vs STORAGE SIZE

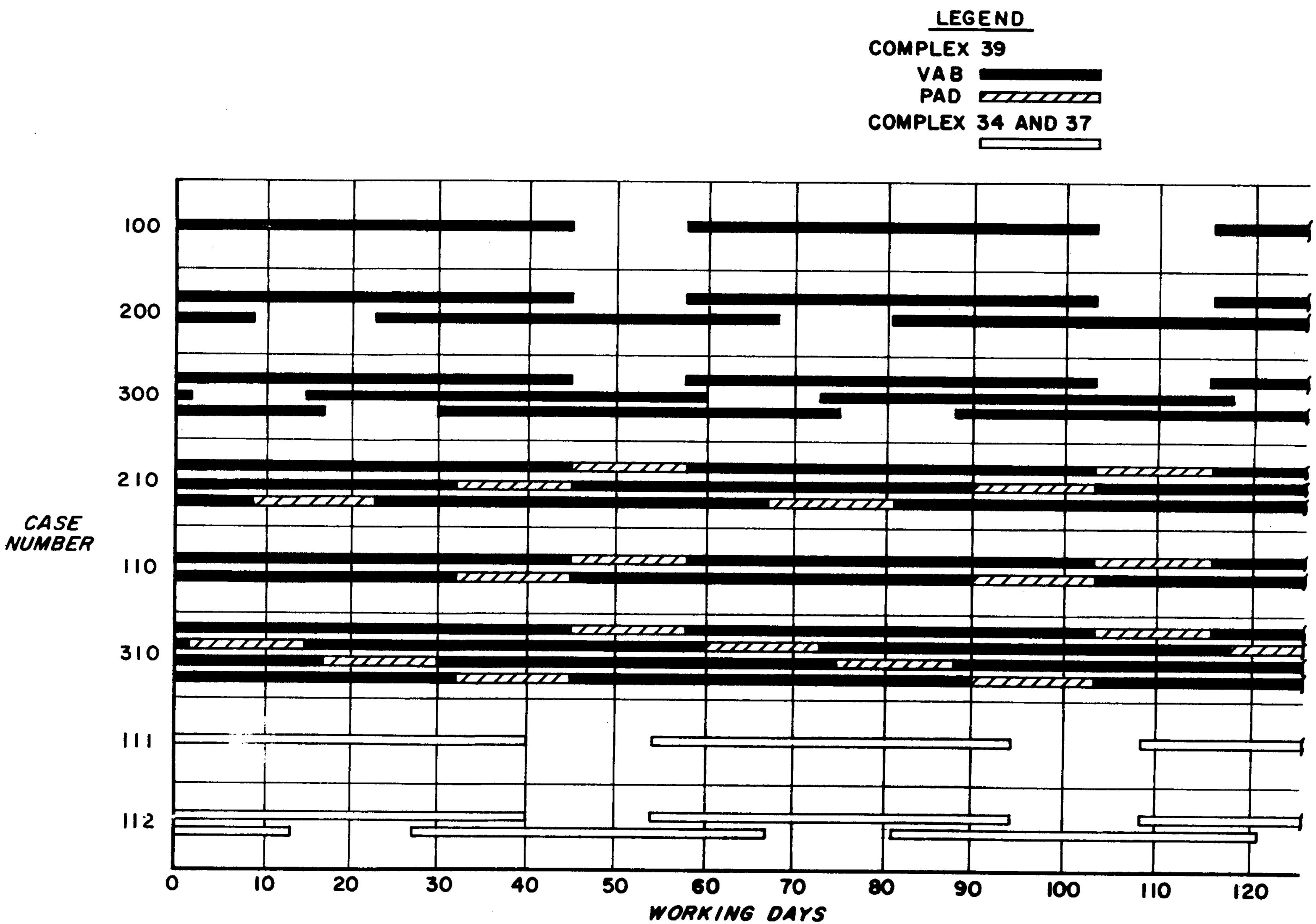
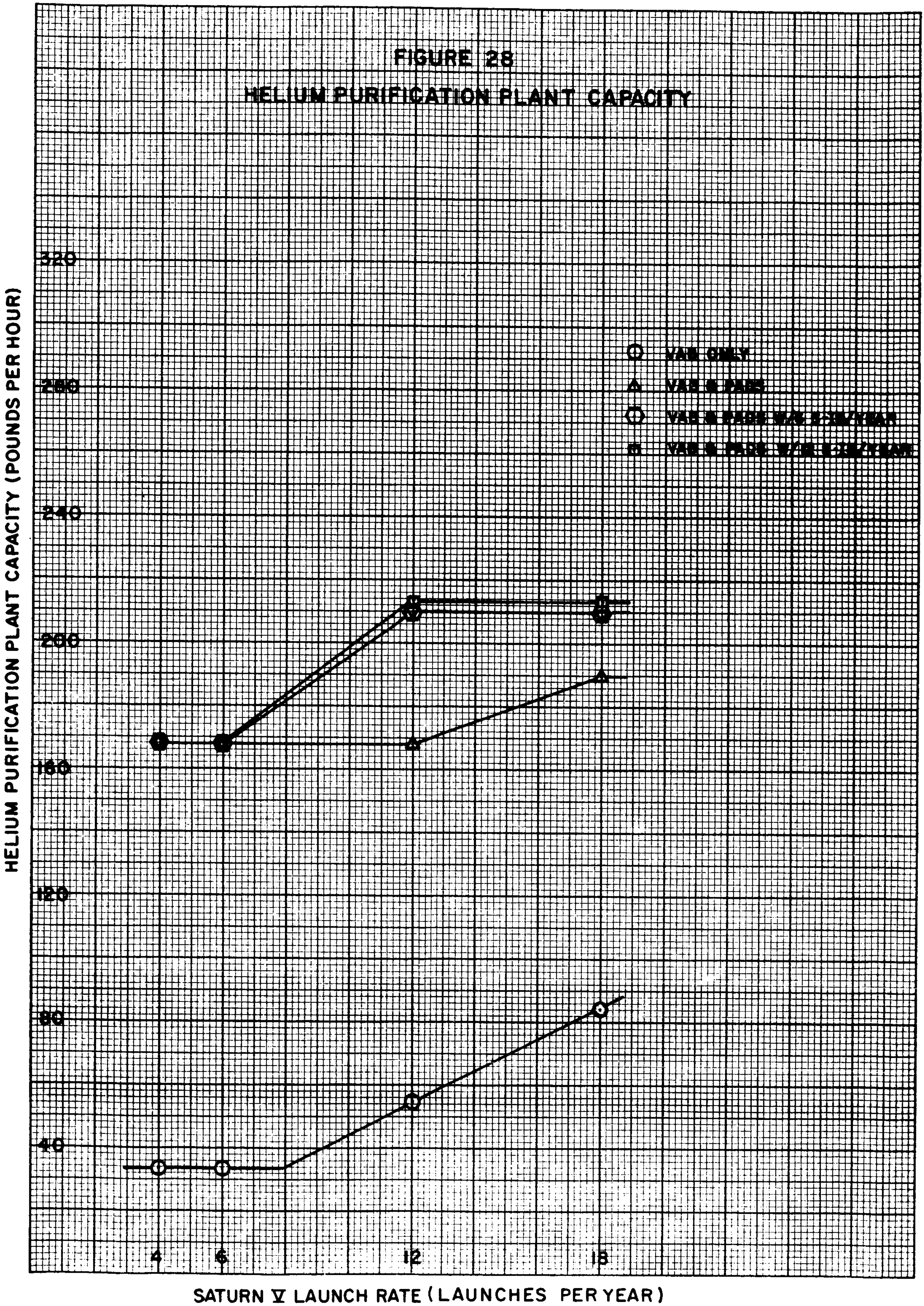


FIGURE 27 OPERATIONAL SEQUENCE WITH VARIOUS VEHICLE DENSITIES

FIGURE 28

HELIUM PURIFICATION PLANT CAPACITY



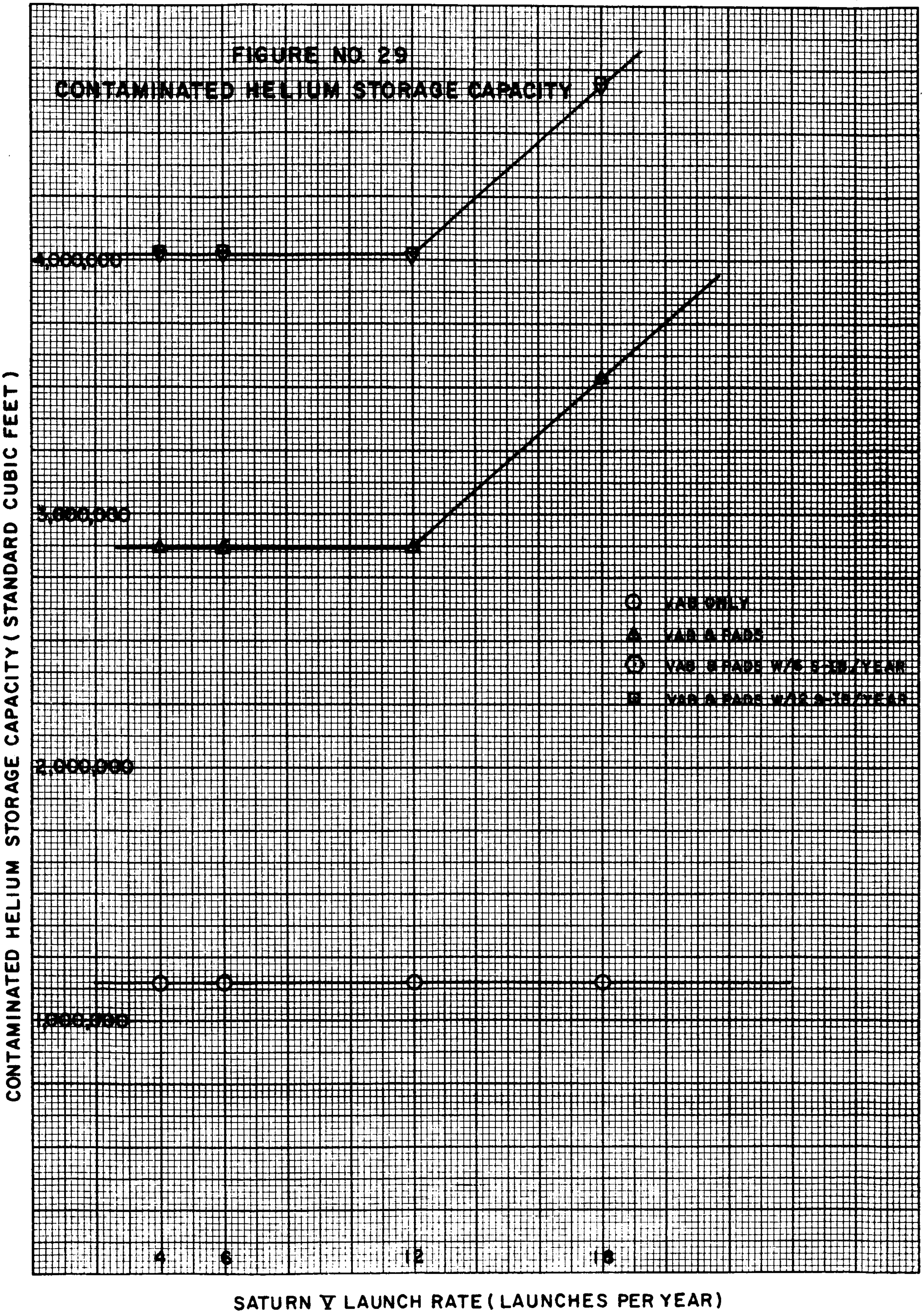


FIGURE NO. 29
CONTAMINATED HELIUM STORAGE CAPACITY

FIGURE NO. 30

TOTAL INVESTMENT OF HELIUM RECOVERY EQUIPMENT

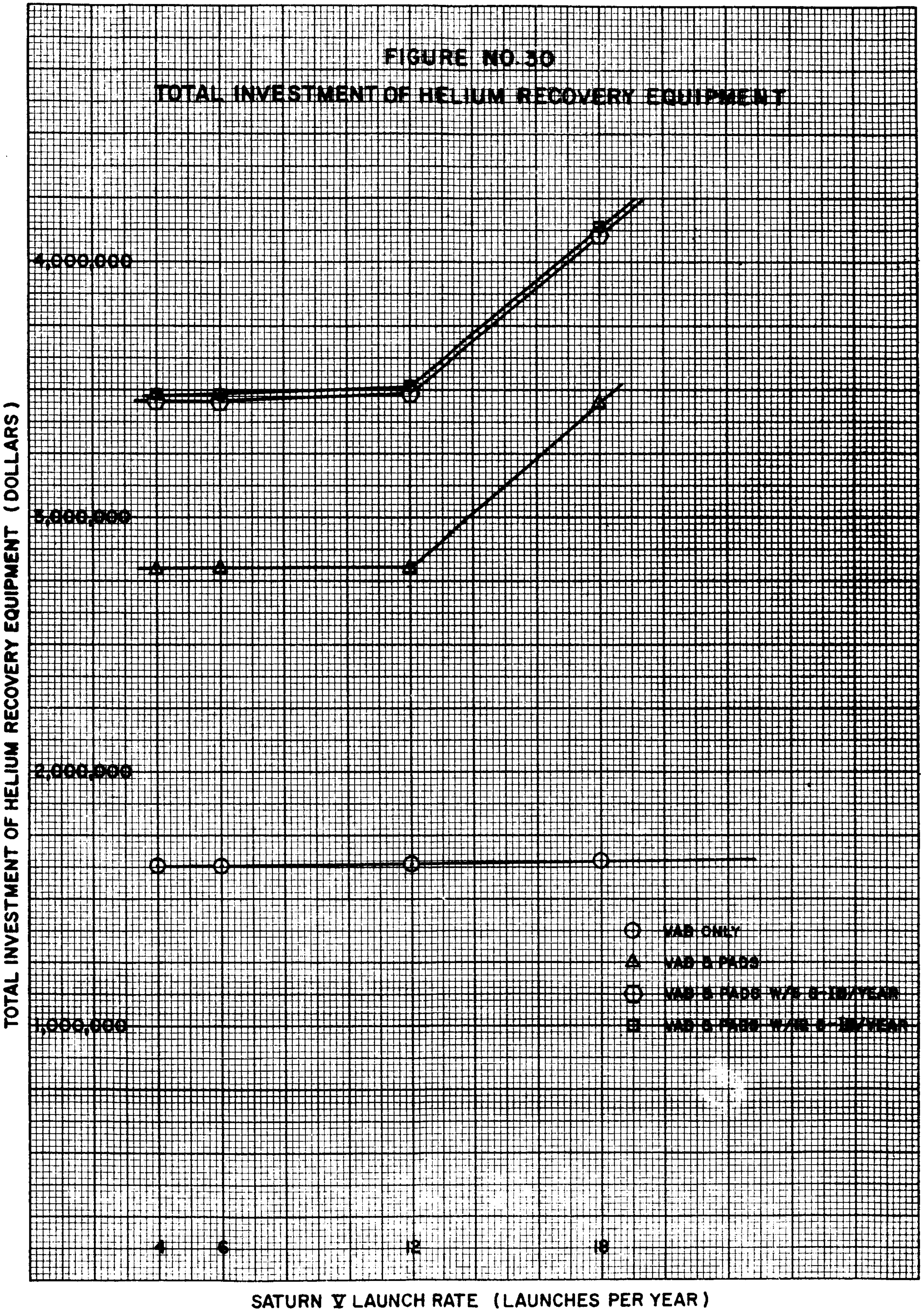
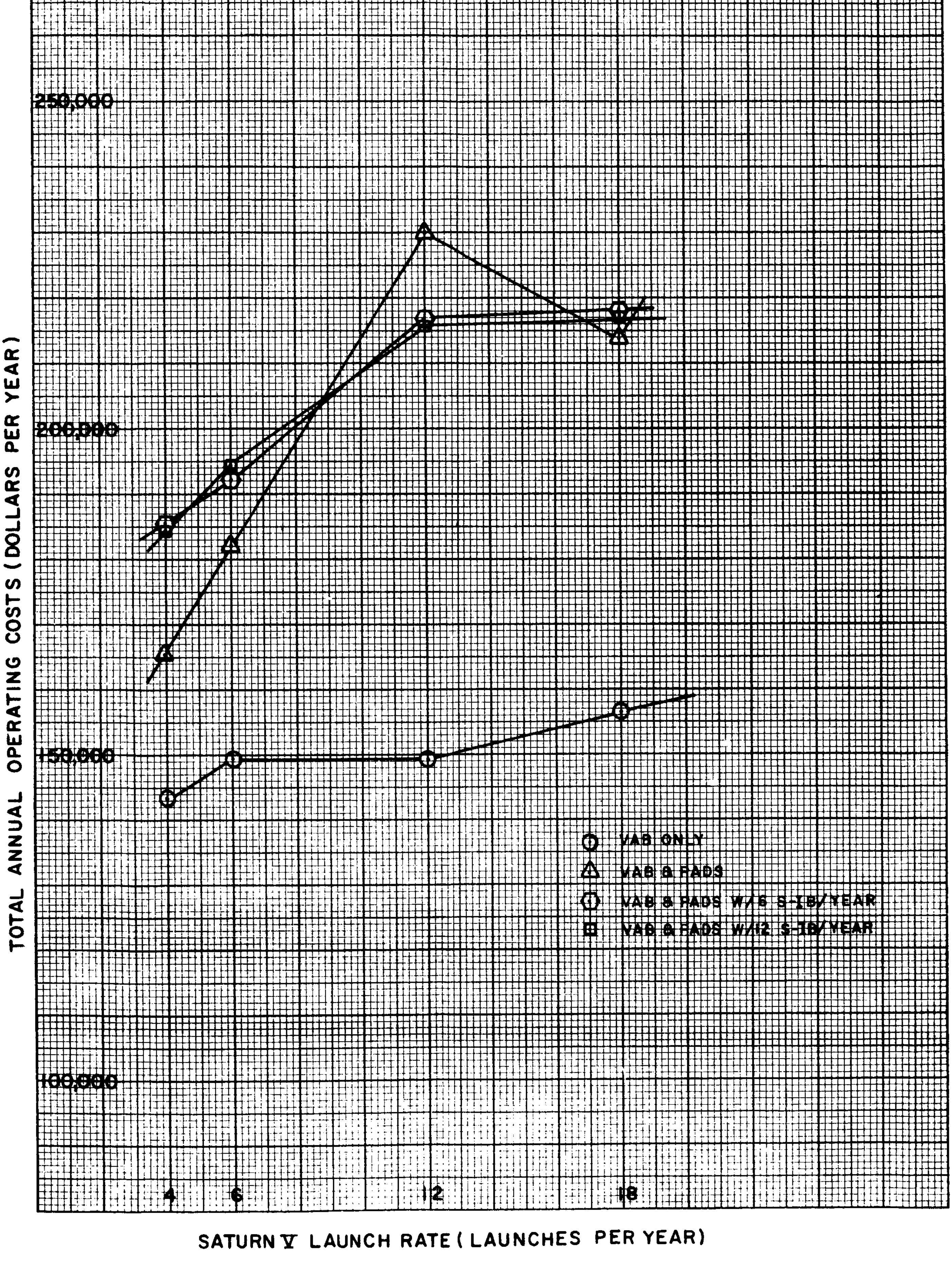


FIGURE NO. 31

TOTAL ANNUAL OPERATING COSTS



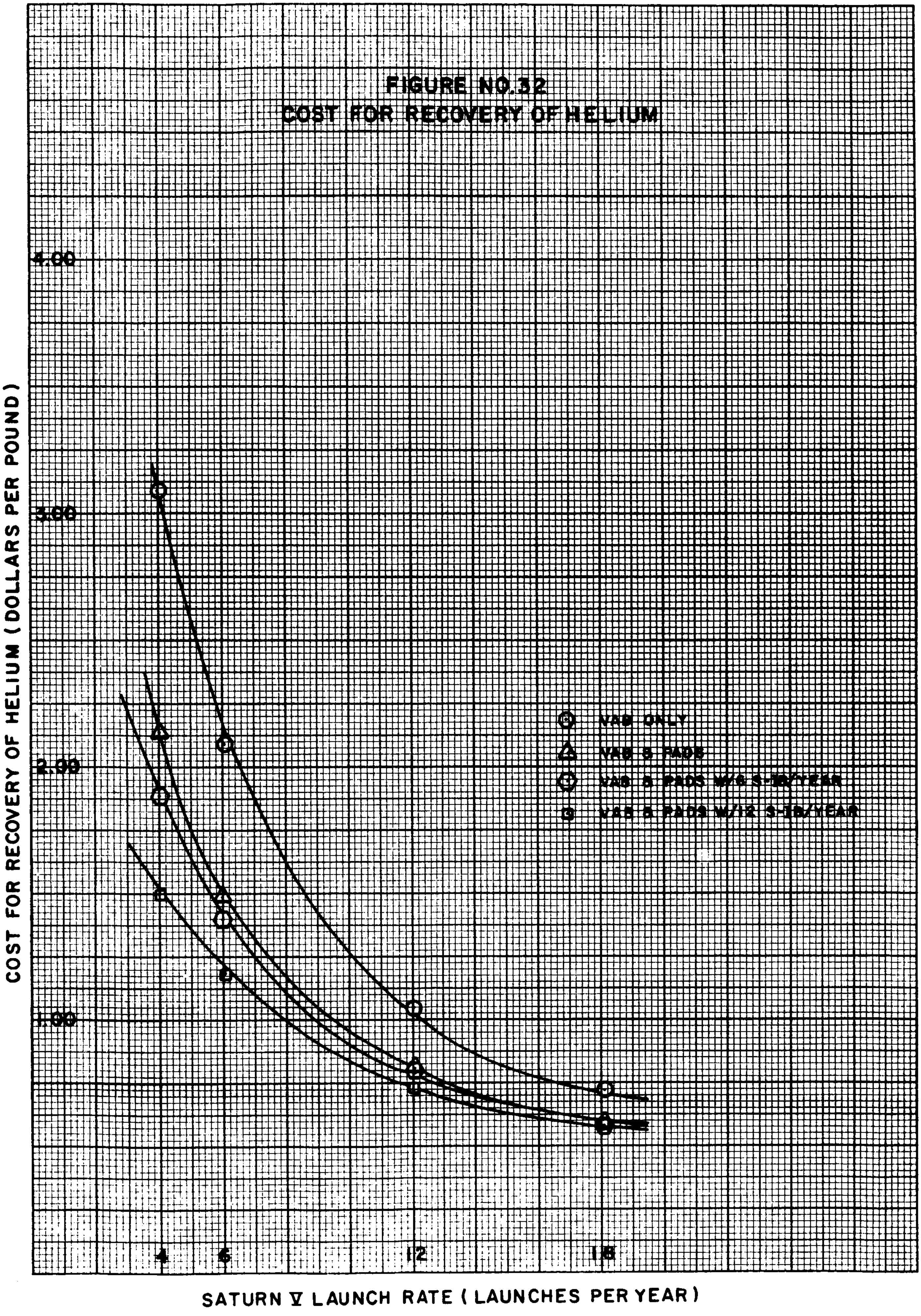
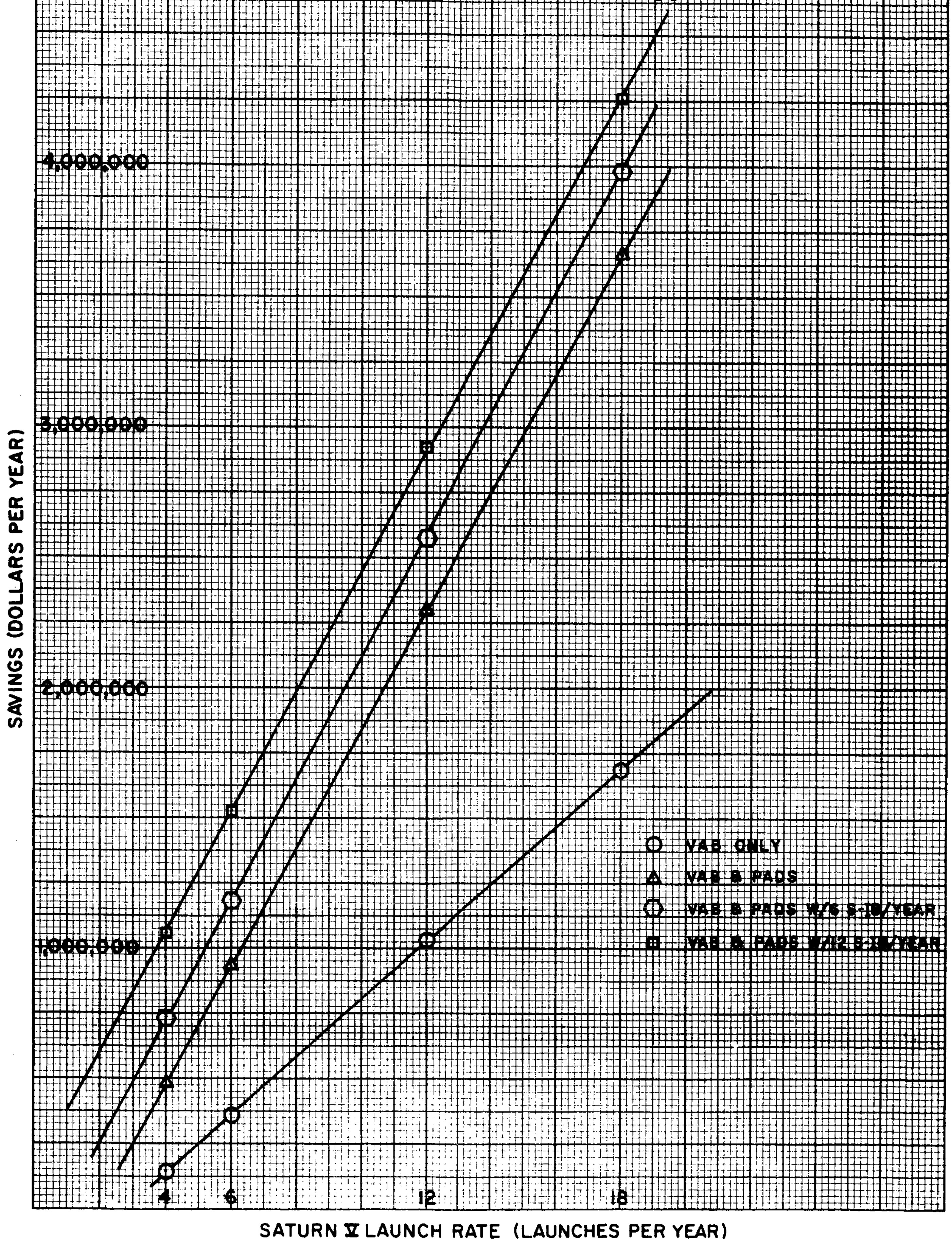


FIGURE NO. 32
COST FOR RECOVERY OF HELIUM

FIGURE NO. 33

ANNUAL HELIUM COST SAVINGS



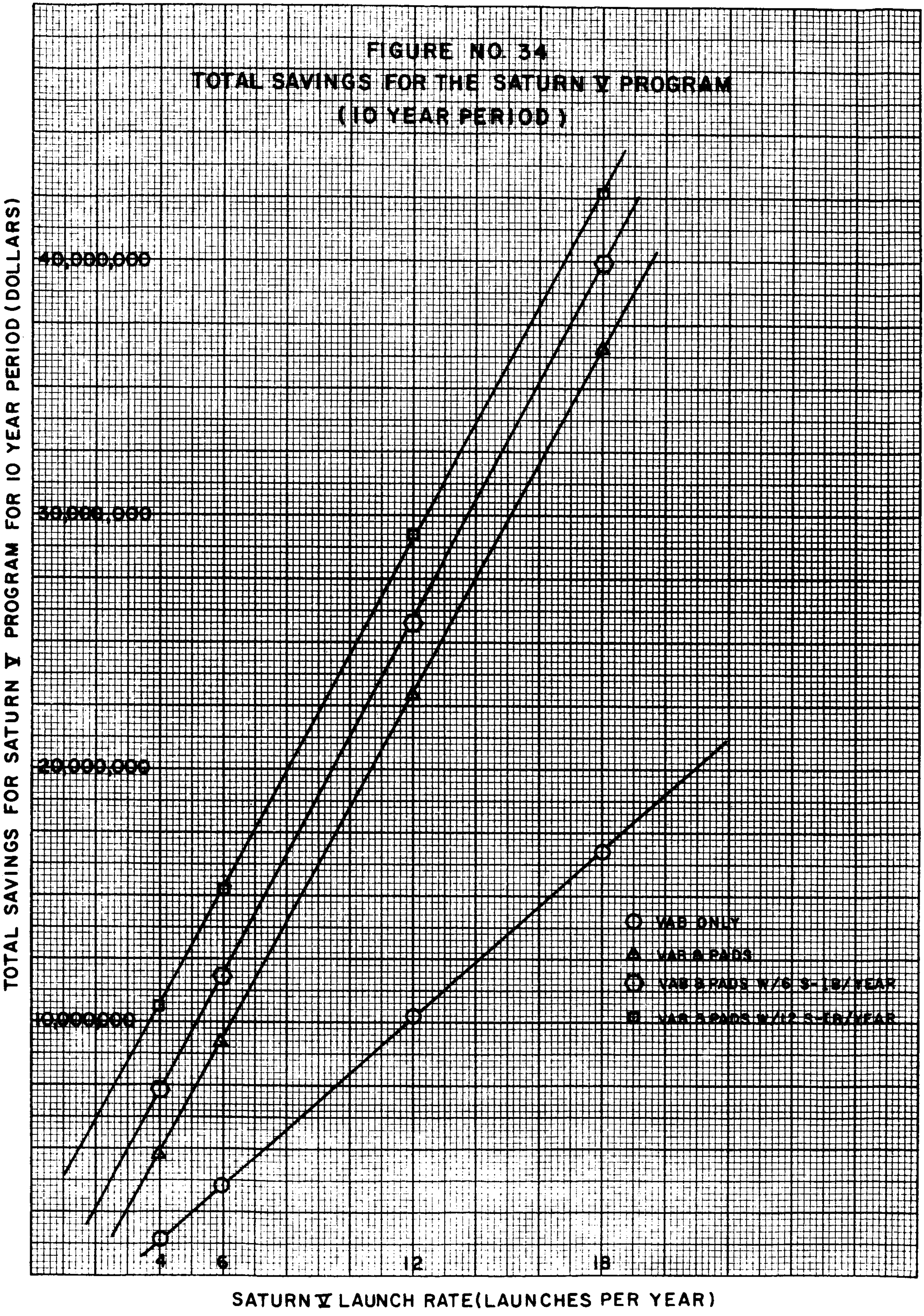


FIGURE NO. 34
TOTAL SAVINGS FOR THE SATURN V PROGRAM
(10 YEAR PERIOD)

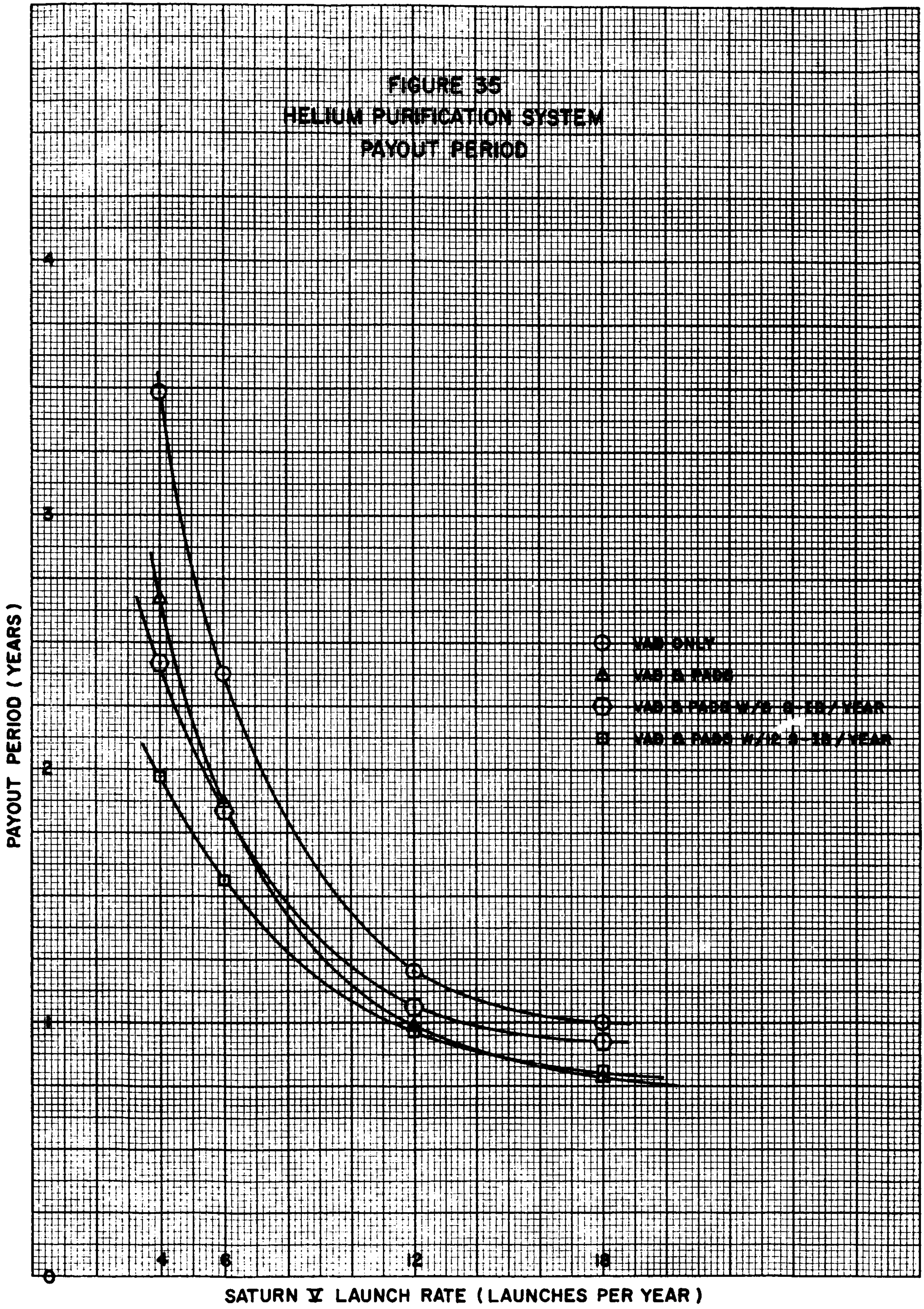
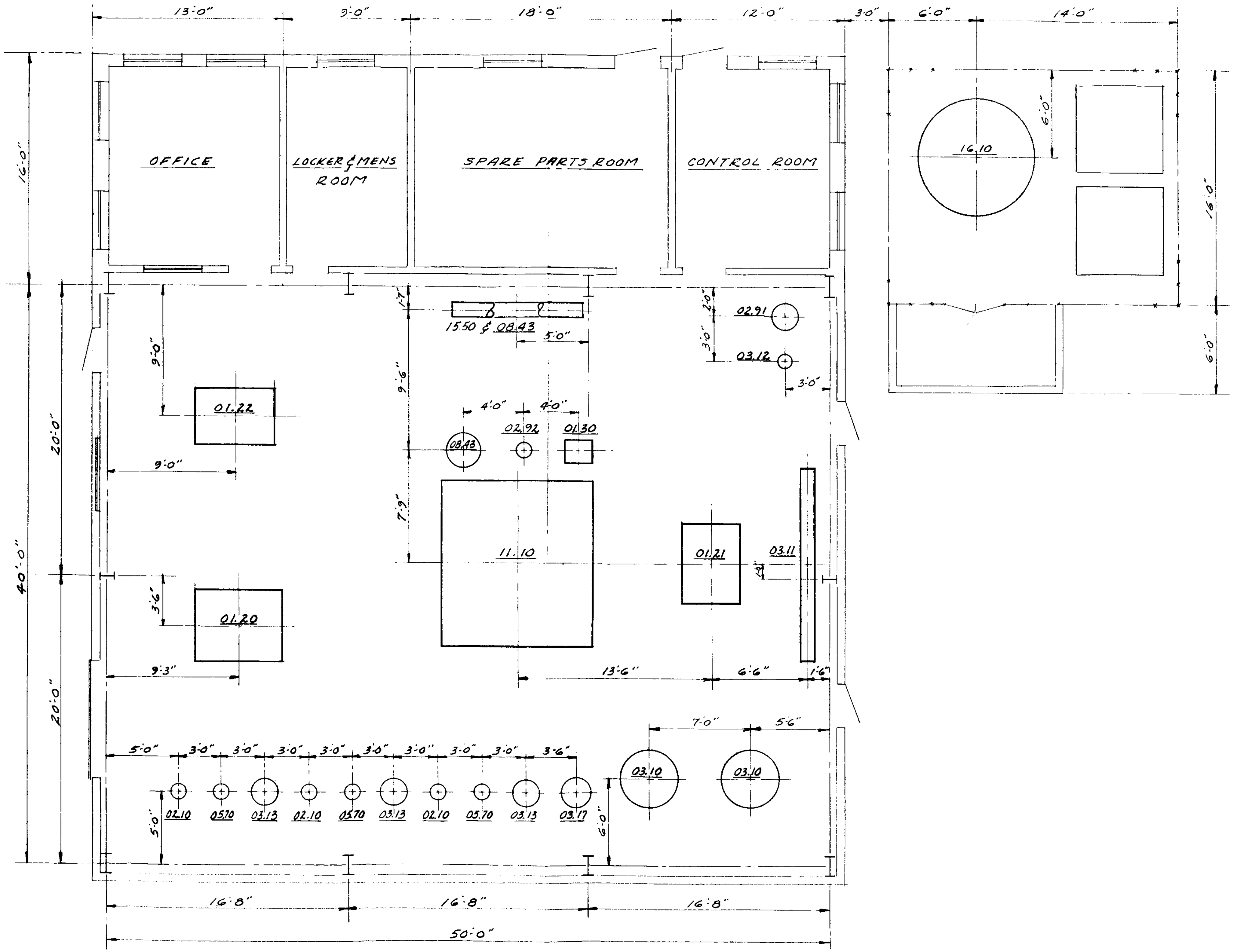


FIGURE 35
HELIUM PURIFICATION SYSTEM
PAYOUT PERIOD
VAB ONLY
VAB & PADS
VAB & PADS W/6 S-IB/YEAR
VAB & PADS W/12 S-IB/YEAR
PAYOUT PERIOD (YEARS)
0
1
2
3
4
4
6
12
18
SATURN V LAUNCH RATE (LAUNCHES PER YEAR)



LEGEND

01.20 MAIN COMPRESSOR
01.21 DRIER REACTIVATION COMPRESSOR
01.22 ADSORBER REACTIVATION COMPRESSOR
01.30 NITROGEN VACUUM PUMP
02.10 DEOXO CONVERTER
02.90 FILTER
02.91 FILTER
02.92 FILTER
03.10 DRIER
03.11 WATER COOLER
03.12 WATER SEPARATOR
03.13 WATER SEPARATOR
03.17 HEATER
05.70 COOLER
08.23 WATER HEATER
08.43 ADSORBER HEATER
15.50 DEFROST WATER HEATER
16.10 LIN STORAGE TANK & VAPORIZERS

REVISIONS

NO.	LETTER	ZONE	DESCRIPTION	DATE	MADE	CHK'D	APPR'D

SK-4-1165-57-1 D

PART NO.	MAT'L. CODE NO.	QTY.	DIMENSIONS	REMARKS	NOMENCLATURE

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE: FRACTION ± DECIMAL ± ANGLES ± HOLE LOCATION ± HOLE SIZE ±

FIRST USED ON 00-4-1165-57.

DRAFTSMAN D.A. HAFER 2-18-65
CHECKED
ENGINEER
APPR'D W.C. ... 2/18/65

TITLE PREL. COMPRESSOR BUILDING LAYOUT FOR HELIUM PURIFICATION EQUIP. NASA CONTRACT No NASA 10-1472

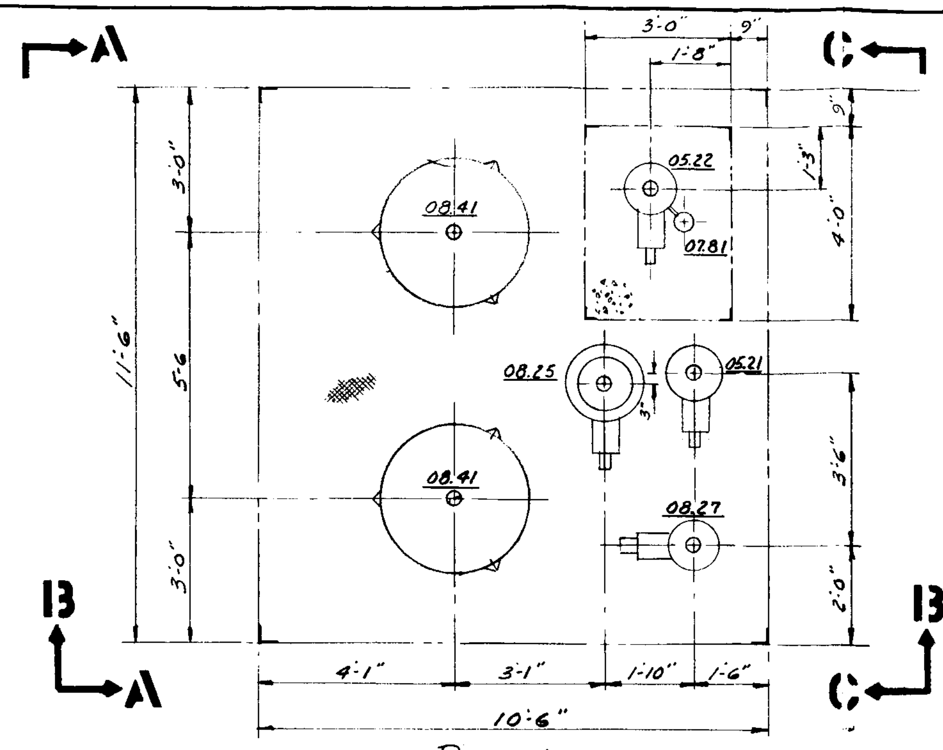
SCALE 1/8" = 1'-0" WT.

AIR PRODUCTS, AND CHEMICALS, INC. ALLENTOWN, PENNSYLVANIA

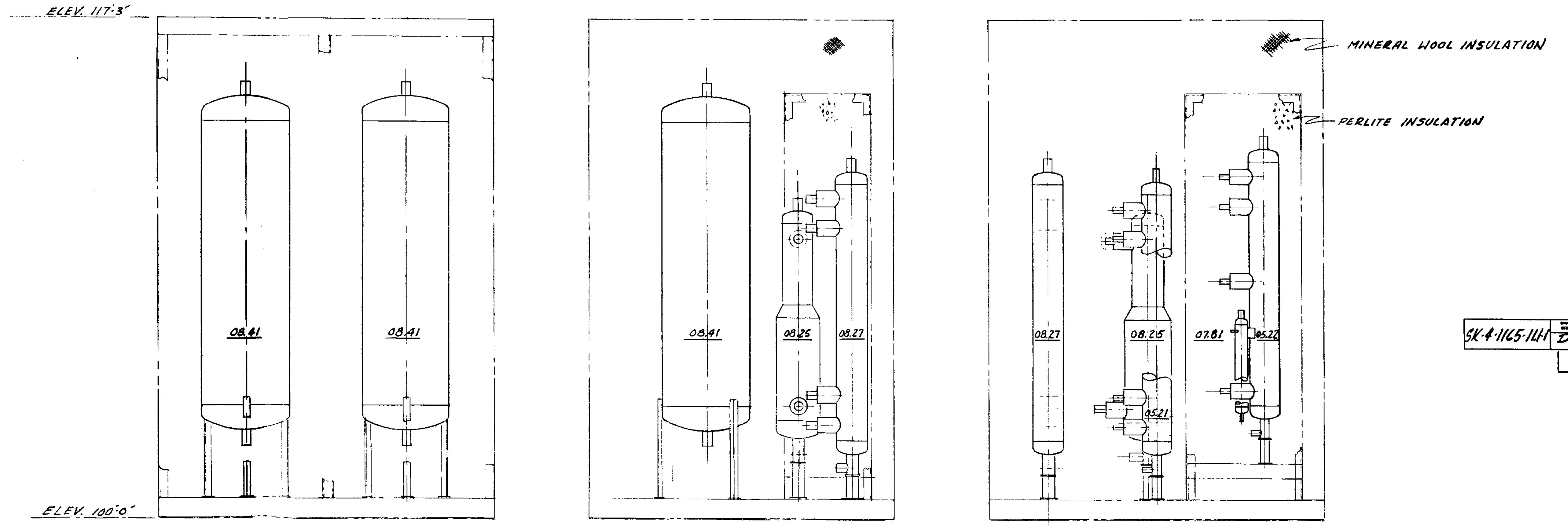
CODE CONTROL NUMBER

SK-4-1165-57-1 D

DIETZGEN 1984 Approved Tracing Paper



PLAN



ELEVATION A-A

ELEVATION B-B

ELEVATION C-C

REVISIONS							
NO.	LETTER	ZONE	DESCRIPTION	DATE	MADE	CHK'D	APPR'D

LEGEND

05.21 MAIN EXCHANGER
05.22 COLD EXCHANGER
07.81 N_2 LIQUID SEPARATOR
08.25 ADSORBER COOLDOWN EXCHANGER
08.27 ADSORBER COOLDOWN ECONOMIZER EXCH.
08.41 N_2 ADSORBER

SK-4-1165-111-1 D

PART NO.	MAT'L. CODE NO.	QTY.	DIMENSIONS	REMARKS	NOMENCLATURE

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE FRACTION * DECIMAL * ANGLES * HOLE LOCATION * HOLE SIZE *

FIRST USED ON 00-4-1165-111

DRAFTSMAN DA/HAFER DATE 2-8-65

CHECKED

ENGINEER

APPR'D WCuhne 2/15/65

TITLE PREL COLD BOX LAYOUT FOR HELIUM PURIFICATION EQUIP NASA CONTRACT Nº NASA 10-1472.

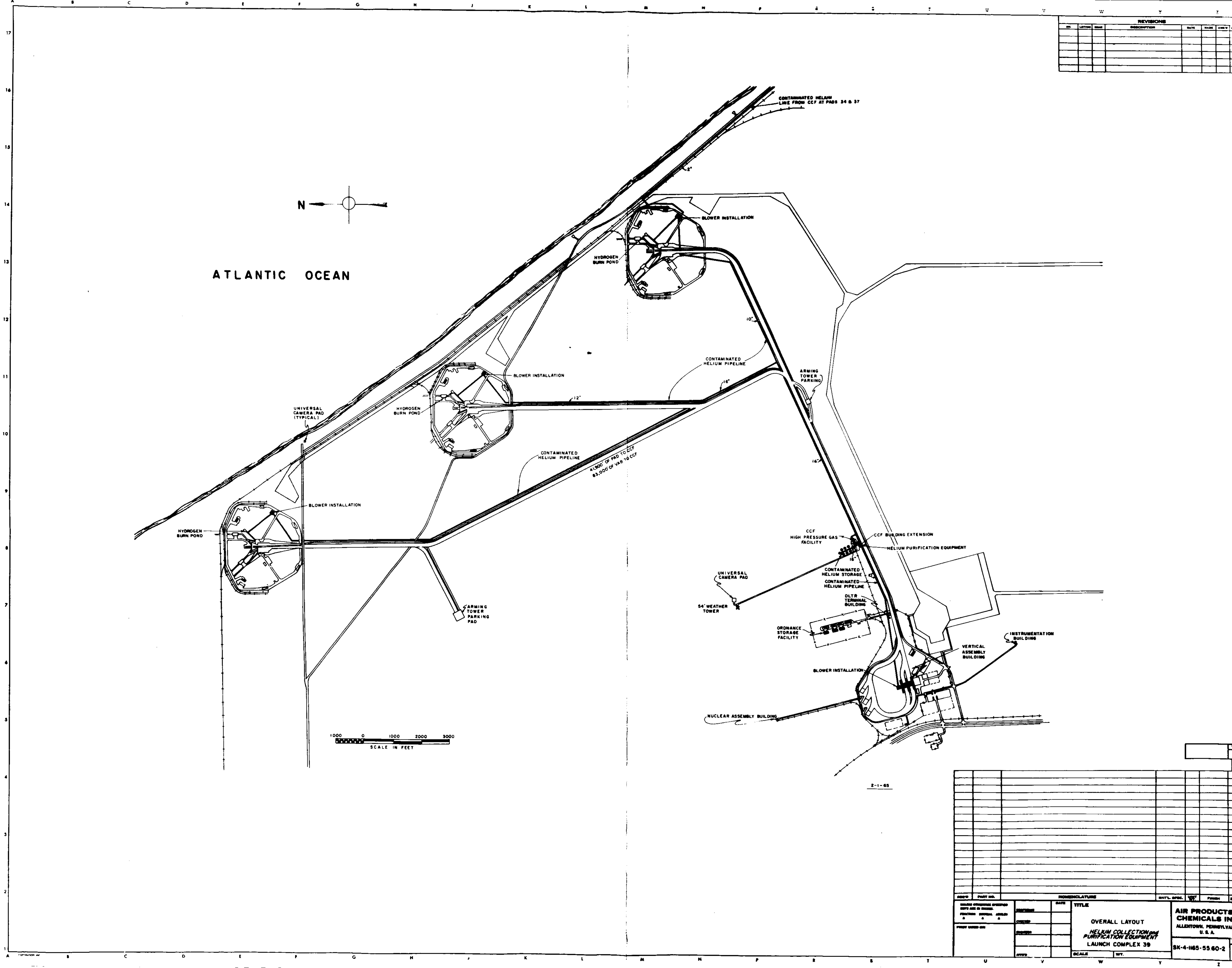
SCALE 1/2" = 1'-0" WT.

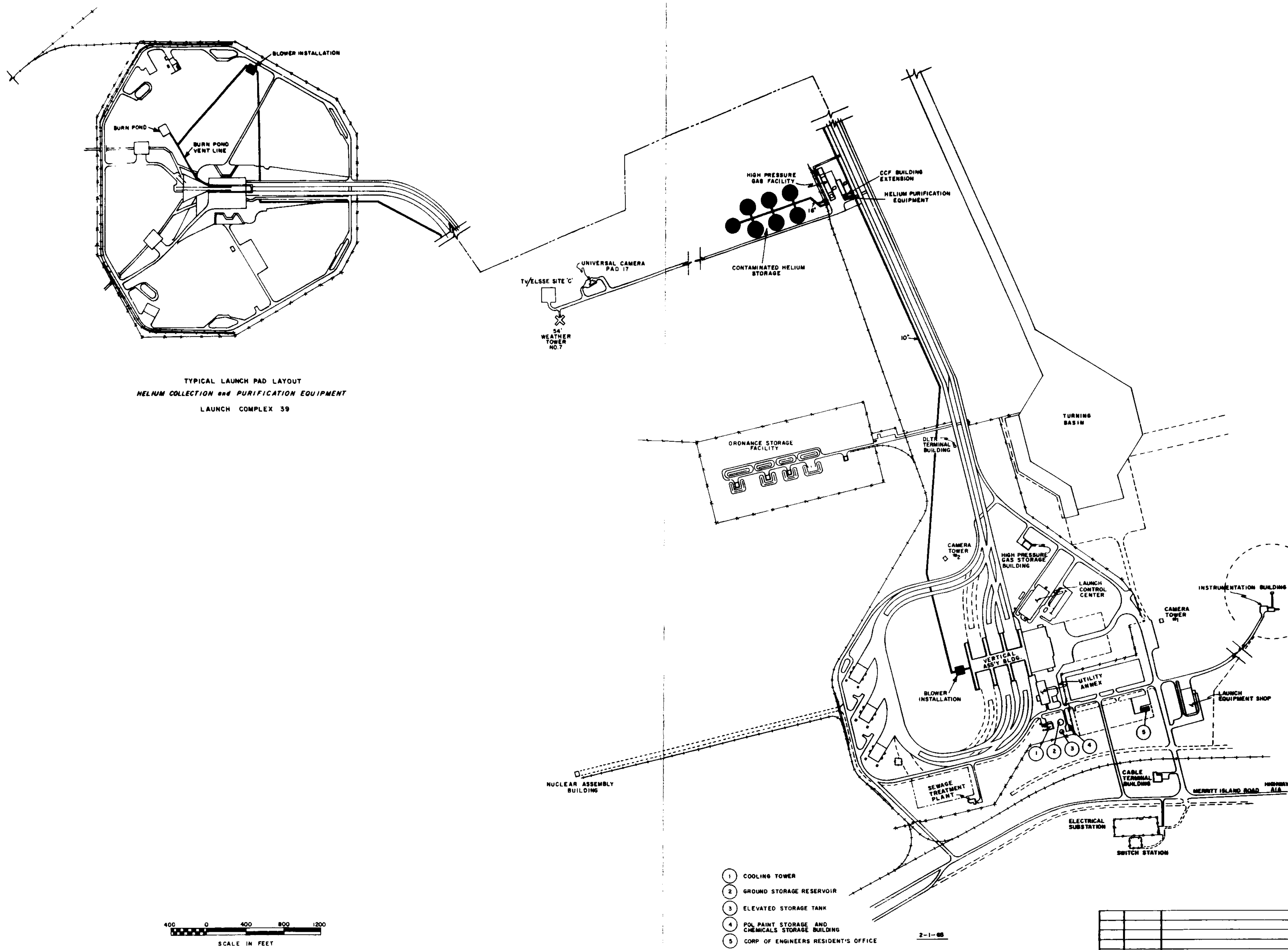
AIR PRODUCTS, AND CHEMICALS, INC. ALLENTOWN, PENNSYLVANIA

CODE CONTROL NUMBER

SK-4-1165-111-1 D

DIETZGEN 196M Approved Tracing Paper 20011


REVISIONS
CONTAMINATED HELIUM LINE FROM CCF AT PADS 34 & 37
N
ATLANTIC OCEAN
BLOWER INSTALLATION
HYDROGEN BURN POND
BLOWER INSTALLATION
HYDROGEN BURN POND
UNIVERSAL CAMERA PAD (TYPICAL)
BLOWER INSTALLATION
HYDROGEN BURN POND
10"
12"
16"
16"
CONTAMINATED HELIUM PIPELINE
CONTAMINATED HELIUM PIPELINE
41,900' OF PAD TO CCF
83,000' OF VAB TO CCF
ARMING TOWER PARKING
ARMING TOWER PARKING PAD
CCF HIGH PRESSURE GAS FACILITY
CCF BUILDING EXTENSION
HELIUM PURIFICATION EQUIPMENT
CONTAMINATED HELIUM STORAGE
CONTAMINATED HELIUM PIPELINE
UNIVERSAL CAMERA PAD
54' WEATHER TOWER
DLTR TERMINAL BUILDING
ORDNANCE STORAGE FACILITY
INSTRUMENTATION BUILDING
VERTICAL ASSEMBLY BUILDING
BLOWER INSTALLATION
NUCLEAR ASSEMBLY BUILDING
1000 0 1000 2000 3000
SCALE IN FEET
2-1-65
NOMENCLATURE
TITLE
OVERALL LAYOUT
HELIUM COLLECTION and PURIFICATION EQUIPMENT
LAUNCH COMPLEX 39
AIR PRODUCTS & CHEMICALS INC.
ALLENTOWN, PENNSYLVANIA U. S. A.
SK-4-1165-55 60-2
E



REVISIONS

TITLE
VERTICAL ASSEMBLY BUILDING, STORAGE and PURIFICATION EQUIPMENT LAYOUT
HELIUM COLLECTION and PURIFICATION EQUIPMENT
LAUNCH COMPLEX 39

AIR PRODUCTS & CHEMICALS INC.
ALLENTOWN, PENNSYLVANIA
U. S. A.

SK-4-1165-55.60-3

E

1. A fifty-eight day check-out and assembly schedule is assumed. During this time the LOX and LH_2 tanks of the S-II and S-IVB stages are kept under a 3 to 5 psig blanket pressure with helium. This pressure is relieved approximately 45 out of the 58 days to accommodate various tests requiring the tanks to be at atmospheric pressure. The blanket pressure of 3 to 5 psig is always applied overnight even if an operation is not completed. During this time, it is possible that an additional purge will be required following the opening of one or more tanks for inspection and/or repair. This opening of the tank is not a normal operation but has occurred in the past.

Specific information applicable to each stage is as follows:

1. S-IC Booster

   a. The helium bottles are pressurized to 1000 to 1500 psig at ambient temperature approximately 40 times for various tests at the VAB.

   b. The bottles are pressurized 3 or 4 times to 1000, 1500 psig and at ambient temperature at the pad and once to 3000 psig at cryogenic temperatures.

   c. The fuel tank is pressure tested to flight ullage pressure at ambient temperatures twice with no RP-1 aboard.

   d. The LOX tank is cycled once at the pad to flight ullage pressure with no LOX aboard, followed by pressure test to the same pressure with LOX aboard.

2. S-II 2nd Stage

   a. The LOX and LH_2 tanks are pressurized to 1/2 flight ullage pressure approximately 20 times for engine checks in VAB.

   b. The helium bottles are pressurized approximately 40 times to 1500 psig for various tests at VAB.

   c. There is a one hour purge of the LOX and LH_2 tanks to achieve -65°F dew point for the calibration of the propellant utilization (P.U.) probe. This purge is accomplished by opening fill-drain valve and purging through pressurization valve.

   d. There is a purge with grade A helium prior to moving vehicle to pad, prior to propellant load tests, and prior to loading for flight.

   e. Purging of the external insulation on LH_2 tank is required prior to propellant load test and prior to flight.

(Table IV). Operating costs vary from $90,125 per year (Table V) for three launches a year to $104,234 per year (Table VI) for six launches a year. Total yearly costs vary from $139,855 for three launches per year to $155,374 for six launches per year respectively (Table VII). Detailed estimated equipment costs are tabulated in Table III.

Since this cycle is the most economical of all considered, it is recommended for further study during Phase III.

4. Case V.

This cycle is capable of processing 46 pounds of contaminated helium per hour from either the VAB or the pad. Total estimated comparative investment, erected, is $418,332; yearly capital charge is $41,833 (Table IV). Yearly operating costs vary from $90,318 (Table V) for three launches per year to $104,408 (Table VI) for six launches per year. Total annual costs, including capital, vary from $141,183 for three launches per year to $156,572 for six launches per year (Table VII). Detailed estimated equipment costs are listed in Table III.

This purification process has been eliminated from the list of possibilities considered as a part of Phase II of the study for the following reasons:

a. The process does not show any marked economic advantage. In fact, it was slightly more expensive than the best case.

b. The reliability of such a system is very questionable, especially when compared to the low-temperature adsorption process. Although other low-temperature purification scrub systems are presently being operated by other companies, these systems are relatively inflexible because they are in continuous operation. In case of a shutdown, it is difficult to restart the units and establish equilibrium conditions. The problem of storing the scrub fluid during shutdown is also serious, since the makeup requirements of ethane can greatly influence system operating costs.

c. Because of the uncertainty of the design involved, especially concerning equilibrium data for the various operating conditions, some minimal amount of development work would have to be performed.

d. A scrub system is generally preferred for higher capacity plants, where the possibility for payout is easier to justify and where continuous operation is more desirable. For a processing plant of the type and size considered for this study, the low-temperature adsorption process appears to be a more standard and acceptable method of purification.

b. Fixed Annual Operating Costs (Continued)

(3) Maintenance at 1.5% of Investment		$ 25,922
	Subtotal	$ 96,101
(4) NASA G&A at 10% of Operating Costs		9,610
	Total	$ 105,711

c. Variable Annual Operating Costs

(1) Power	VAB - 35 KW, Pad - 21 KW		$ 535
(2) Water	VAB - 630 GPH, Pad - 1040 GPH		110
(3) LIN	VAB - 20 GPH, Pad - 20 GPH		3,828
(4) LOX	Pad only - 290 SCFH		242
(5) Equipment Moving Costs			80
		Subtotal	$ 4,795
(6) NASA G&A at 10% of Operating Costs			480
		Total/Launch	$ 5,275

d. Trend Tabulations

No. of Launches Per Year	Annual Capital Charges	Annual Fixed Oper. Cost	Annual Variable Oper. Cost	Total Annual Cost	Wt. of Helium Recovered	Cost of Recovery $/lb.
1	$172,815	$105,711	$ 5,275	$283,801	52,114 lb	$ 5.45
2	172,815	105,711	10,550	289,076	104,228	2.77
3	172,815	105,711	15,825	294,351	156,342	1.88
4	172,815	105,711	21,100	299,626	208,456	1.44
5	172,815	105,711	26,375	304,901	260,570	1.17
6	172,815	105,711	31,650	310,176	312,684	.99

4. Alternate 4

Alternate 4 involves the purification of helium at the location of its use. The purified helium is then to be compressed into trailers at 6,000 psi for delivery to the compressor-converter facility (CCF), where the helium would be introduced into the system by the CCF compressors at 6,000 psi. Using 6,000-psi trailers, the gas must be compressed to a maximum of 6,000 psi for filling. Since the storage at the VAB

c. Blower to move contaminated helium through pipeline.

d. Low-pressure piping from each pad to the storage at this area's CCF.

4. Alternate D (Figure 21).

a. Fixed low-pressure storage of 1,000,000 SCF (10,000 lb.) located at this area's CCF.

b. Mobile helium purification plant for use part-time at a prepared site near this area's CCF.

c. Low-pressure piping from each pad to the storage at this area's CCF.

B. DISCUSSION

1. Alternate A (see Figure 18).

The contaminated helium is piped from its place of use at either Complex 34 or Complex 37 to a low-pressure storage container at this area's CCF. The gas is then purified in a fixed purification plant, using cycle IV, and made available for reuse.

2. Alternate B (see Figure 19).

The contaminated helium is piped from its place of use to a low-pressure storage container at this area's CCF. The gas is then compressed into 6,000-psi trailers for transportation to the contaminated storage at Complex 39 for processing in that area. Four trailers will be required for this transportation.

3. Alternate C (see Figure 20).

The contaminated helium is piped from its place of use to a low-pressure storage container at this area's CCF. From this storage, the gas is moved at a steady rate through a low-pressure pipeline to the contaminated storage at Complex 39 for processing in the purification plant there.

4. Alternate D (see Figure 21).

The contaminated helium is piped into a low-pressure storage container located at this area's CCF. A mobile purification plant purifies the stored gas between its operations at Complex 39. The purified gas is then introduced into the Saturn V system by the compressors in that CCF.